University Of Khartoum

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Global warming

Case Study: Carbon Dioxide Emissions from Cement Industry in Atbara

A Thesis Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Science in Chemical Engineering.

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Dedication

I dedicate this research to the most important two people to me, the people whose entire life was devoted and made available to be what I am and to achieve what I have successfully achieved. With all my love and appreciation, I dedicate this research to my parents, Ahmed Mahmoud Awad and Fatimah Dyab.

To my sisters; Amani, Amal, Dalia and Rania and to my only beloved brother Ayman, I dedicate this research to them as they have inspired and helped me with all the support I needed throughout my life. Indeed, their significance and existence in my life added a new flavor to it, without them, I could have not been what I am now.

To my only love, and love forever, my husband Ibrahim, I dedicate this research to him as his endless support and wise suggestive inputs were a major significant factor to the success and completion of this research paper.

I finally conclude by dedicating this research paper to my children; the light that I see the world through, and the ambition that I portray the future with; Ahmed, Amal and Yousif.

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Abstract

The objective of this research is to explore the contributions of cement industry to global warming with special reference to the flourishing and rapidly growing Cement industry in Sudan.

International agreements were discussed and mathematical models for the representation of climate change were developed. As a case study, emissions of Carbon dioxide from Atbara cement factory were calculated and analyzed through collection of the necessary information on the productivity of the factory, fuel types and the properties of raw materials used in cement production. Molecular weights, used carbon fuel combustion equations and calcinations processes were utilized in the calculation of CO_2 emissions. The second method has been used for recalculation with the assumption of pre-heaters addition and the utilization of fuel alternatives.

The results obtained revealed that, using natural gas, five stage pre-heaters and raw materials with low organic subestances contributes the best to the positive performance.

The study recommended continuing dissemination of global warming and climate change culture and information to different concerned parties. To reduce the influence and contribution of cement industry to global warming, it is recommended to add a pre-heater to kilns, use natural gas as an alternative fuel instead of furnace, develop alternative cement to replace the costly and pollutant Portland cement. It is also recommended to look for ways and means to minimize carbon dioxide emission or through absorption and use of absolute ethanol or blend thereof.

مستخلص

يهدف البحث الى استكشاف مساهمة صناعة الأسمنت فى الانبعاث الحرارى من خلال دراسة انبعاث غاز ثانى اكسيد الكربون الناتج عن عمليات الكلسنة واحتراق الوقود مع التركيز على صناعة الاسمنت السودانية المتسارعة النمو.

تمت مناقشة محتوى الاتفاقيات العالمية فى المجال كما تم التطرق واختيار نماذج رياضية لمحاكاة عملية التغير المناخى. و حساب كمية ثانى اكسيد الكربون المنبعثة من احتراق الوقود و عمليات الكلسنة وذلك بجمع المعلومات اللازمة عن انتاج المصنع ونوع الوقود ومحتواه الحراري ومواصفات الخام المستخدم فى صناعة الأسمنت- مصنع أسمنت عطبرة كدراسة حالة. وذلك باستخدام الاوزان الجزيئية ونسبة الكربون ومعادلات الاحتراق والكلسنة. كما اجريت نفس الحسابات السابقة بافتراض استخدام بدائل الوقود عند اضافة مسخن أولي (pre-heaters).

اوضحت نتائج البحث ان استخدام الغاز الطبيعي يقلل من زيادة غاز ثانى اكسيد الكربون مقارنة مع بعض أنواع الوقود الأخرى كما ان اضافة مسخنات أولية (pre-heaters) واستخدام مواد خام شبه خالية من المواد العضوية يقلل من استهلاك الوقود وبالتالى يقلل من انبعاث غاز ثانى اكسيد الكربون.

اوصت الدراسة بمواصلة بث ثقافة البيئة والاحتباس الحرارى لمختلف الجهات وذلك للاسهام فى تقليل الانبعاثات. كما اوصت بأن يتم استخدام الغاز الطبيعى كوقود واضافة مسخن أولي للفرن وانتاج اسمنت مخلوط بدلاً من البورتلاندى فى الحالات التى تستدعى ذلك والبحث عن طرق لتقليل من ثانى اكسيد الكربون المنبعث إلى الحد الأدنى عن طريق الامتصاص أو استعمال الايثانول المطلق أو خلطه منه.

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List of abbreviations

GHGs	greenhouse gases
ppm	parts per million
IPCC	Intergovernmental Panel on Climate Change
CFC	chlorofluorocarbons
WMO	World Meteorological Organization
IMO	International Meteorological Organization
UNEP	United Nations Environment Programme
IPCC	Intergovernmental Panel on Climate Change
UNFCCC	UN Framework Convection on Climate Change
WG1	IPCC Working Group I
WG2	IPCC Working Group II
WG3	IPCC Working Group III
TFI	Task Force on National Greenhouse Gas Inventories
IPCC-NGGIP	IPCC National Greenhouse Gas Inventories Programme
TGICA	Task Group on Data and Scenario Support for Impacts and Climate Analysis
TGCIA	Task Group on Scenarios for Climate and Impacts Assessment
DDC	IPCC Data Distribution Centre
GCMs	global climate models
CCS	Carbon Capture and Storage
PHP	preheating and pre-calcinations kilns

1. Introduction

1.1 General

Sometimes, it is hard to define global warming in a fancy way or with the usage of scientific terminologies since it is a problem that, every person should be award of. However, the best way to define it is to point toward it and prove its existence. The problem of global warming is sensed and seen in every part of the planet. The melting of the glaciers, the rising of the sea levels, the drying of the forests, the destruction of the wildlife, and the overall heating of the planet are all indicating factors to global warming. Simply stated, all the results of these factors are called global warming. It is causing a set of changes to the Earth's climate, or long-term weather patterns that varies from place to place. As the Earth spins each day, the new heat swirls with it, picking up moisture over the oceans, rising here, settling there. It is changing the rhythms of climate that all living things have come to rely upon.

Is the global warming real or it just has been exaggerated? The easiest and the most straightforward answer to the addressed question are to look up past records about the temperature measurements. Dramatic changes in the overall temperature have been found. Examining the sediments could be another way to test its truth. Sediments preserve all these bits and pieces, which contain a wealth of information about what was in the air and water when they fell. Scientists reveal this record by inserting hollow tubes into the mud to collect sediment layers going back millions of years. Moreover, trees store information about the climate in the place where they live. Each year, trees grow thicker and form new rings. In warmer and wetter years, the rings are thicker. Old trees and wood can tell us about conditions hundreds or even several thousands of years ago.

For a direct look at the atmosphere of the past, scientists drill cores through the earth's polar ice sheets. Tiny bubbles trapped in the gas are actually pieces of the earth's past atmosphere, frozen in time. That's how the concentrations of greenhouse gases are known since the industrial revolution are higher than they've been for hundreds of thousands of years. Computer models help scientists to understand the Earth's climate, or long-term weather patterns. Models also allow scientists to make predictions about the future climate. Basically, models simulate how the atmosphere and oceans absorb energy from the sun and transport it around the globe.

Global warming has been causing the most controversial debates nowadays from the political standpoint as well as the economic standpoint. Surprisingly enough, presidential candidates in the United States of America have been using it as a winning token when running for the presidency such as Al Gore, who let the masses know about global warming in his documentary “The Inconvenient Truth”. This research work is shaded light into the global warming problem, its historical background, its effects and causes, present scientific results, and list solutions in order to overcome the problem.

1.2 Objectives

1.2.1 General objective

- To study different international agreements concerning the climate change and CO_2 emission with respect to cement industry.

1.2.2 Specific objectives

- Investigate the influence and contribution of Atbra cement industry on the climatic changes and environment.
- Propose research plans to minimize CO_2 emission from Cement industries**.**
- Review and simulate the mathematical modeling of climatic change.

2. Literature Review

2.1 General

People always confuse between climate and weather. Simply stated, climate can be thought of as a long-term average weather. Observations can show that there have been changes in weather, and its statistics of changes in weather over time that identify climate change, while weather and climate are closely related, there are important differences. A major difference between weather and climate is that weather is unpredictable phenomenon due to its chaotic nature, whereas climate is a much more manageable issue. A major limiting factor to the predictability of weather beyond several days is a fundamental dynamical property of the atmosphere, nevertheless, meteorologists are able to predict the weather successfully several days into the future using physics-based concepts that controls how the atmosphere moves, warms, cools, rains, snows, and evaporates water. [1]

2.2 The History of the Earth temperatures change

It has been mentioned previously in other sections of this paper that the overall temperature of Earth has been changing, a good question to ponder upon perhaps would be; how is that happening? By this question, it is meant to present some statistical, historical data along with a small discussion.

Surface temperatures have increased by about $0.74^{o}C$ over the past hundred years, and that is between 1906 and 2005 as indicated in the figure below, Figure 2.1. However, this warming has been neither steady nor the same in different seasons or in different locations. There was not much overall change from 1850 to about 1915, aside from ups and downs associated with natural

variability but which may have also partly arisen from poor sampling. For the most part, warming in the last century has occurred in two phases; phase one was from the 1910s to the 1940s with an average of 0.35^{o}C followed by a slight cooling of 0.1^{o}C, phase two was warmer than phase one and it was from the 1970s to the end of 2006 with an average of 0.55^{o}C. An increasing rate of warming has taken place over the past 25 years, and the last 12 years have been recorded to be the warmest so far. Warming, particularly since the 1970s, has generally been greater over land than over the oceans. Seasonally, warming has been slightly greater in the winter hemisphere.

Above the surface, the atmosphere is divided into four horizontal layers; troposphere, stratosphere, mesosphere, and thermosphere. The troposphere and stratosphere are characterized by decreasing temperature. Mesosphere and thermosphere are characterized by decreasing temperature. The troposphere is usually very turbulent place; that is, there are strong vertical air movements that lead to rapid and complete mixing. This mixing is good for air quality since it rapidly disperses pollutants. Above the troposphere is a stable layer of very dry air called the stratosphere. Pollutants that find their way into the stratosphere may remain there for many years before they eventually drift back into the troposphere, where they can be more easily diluted and ultimately removed by settling or precipitation in the stratosphere, short wavelength ultraviolet energy is absorbed by ozone O_3 and Oxygen O_2, causing the air to be heated. The resulting temperature inversion is what causes the stratosphere to be so stable. The troposphere and stratosphere combined account for about 99.9% of the mass of the atmosphere. Together they extend only about 50 km above the surface of the Earth, a distance equal to less than one percent of Earth's radius. Since 1950s, the most reliable sets of data show that the troposphere has warmed at a slightly greater rate than the surface, while the stratosphere has cooled markedly since

1979. This agrees with the physical expectations and most model results, which demonstrate the role of increasing greenhouse gases in tropospheric warming and stratospheric cooling; ozone depletion also contributes substantially to stratospheric cooling. The figure below represents a graphical explanation in support with the discussion above.

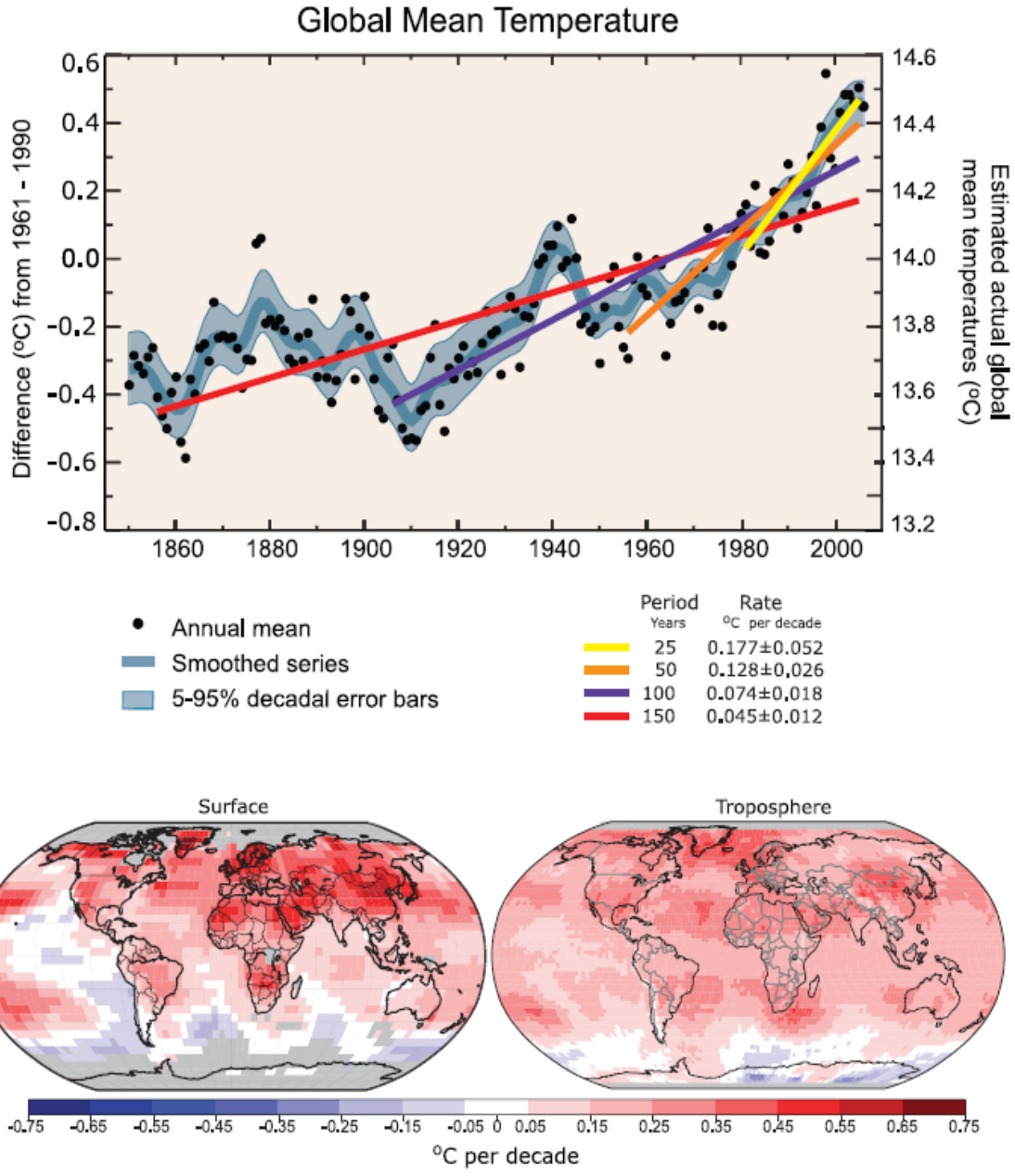

Figure 2.1 Global Warming Data [4]

The top graph shows the annual global mean observed temperature represented by the black dots along with simple fits to the data. The left hand axis shows anomalies relative to the 1961 to 1990 average and the right hand axis shows the estimated actual temperature in ^{o}C. Linear trend fits to the last 25 (yellow), 50 (orange), 100 (purple) and 150 years (red) are shown, and correspond to 1981 to 2005, 1956 to 2005, 1906 to 2005, and 1856 to 2005, respectively. Note that for shorter recent periods, the slop is greater, indicating accelerated warming. Patterns of linear global temperature trends from 1979 to 2005 estimated at the surface (bottom left), and for the troposphere (bottom right) from the surface to about 10 km altitude, from satellite records. Grey areas indicate incomplete data. [2]

2.3 Factors Affecting Earth's Climate

From a scientific prospective, the climate can be considered as a system, and like any other system, it consists of components and there exist factors that influence its performance. The climate system is a very complex one whose components are very interactive. The components of the climate system include, but not limited to, the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. For the most part, the atmospheric component of the climate system characterizes the climate. As mentioned previously, climate is defined as average weather, therefore, it could be redefined as the mean and the variability of temperature, precipitation and wind over a period of time, this period of time is classically known to be 30 years. The factors that affect the climate system are in two categories; internal dynamics of the system itself, and external factors. The external factors are called forcing and include natural phenomena such as volcanic eruptions and solar variations, as well as human-induced changes in atmospheric composition.

The climate system is dominated by the solar radiation, i.e. radiation balance of earth. There are three main ways in which this radiation balance can be altered; First, by changing the incoming solar radiation, such as changes in Earth's orbit or in the Sun itself, second, by changing the fraction of solar radiation that is reflected called 'albedo', an example for that would be changes in cloud cover, atmospheric particles or vegetation, and the third way is by altering the long wave radiation from Earth back toward space, and one way this could be achieved by changing the greenhouse gas concentrations.

The external factors, or the forcing, are responded via a variety of feedback mechanisms. The response varies from factor to another and could be either direct or indirect. These feedback mechanisms can either amplify or diminish the effects of a change in climate forcing. If a feedback mechanism were amplifying, it would be called a positive feedback; otherwise, it is a negative feedback. For example, as rising concentrations of greenhouse gases warm Earth's climate, snow and ice begin to melt. This melting reveals darker land and water surfaces that were beneath the snow and ice, and these darker surfaces absorb more of the Sun's heat, causing more warming, which causes more melting, and so on, in a self-reinforcing cycle. This feedback loop, known as the 'ice-albedo feedback', amplifies the initial warming caused by rising levels of greenhouse gases. On the other hand, increasing on CO_2 concentration causes more radiative forcing, which would increase the Earth's surface temperature. As the temperature goes up, water vapor could mean more cloud ness, and that could cause an increase in the albedo. Increasing the albedo reduces the solar energy reaching the Earth and would tend to offset the original warming, and this is caused a negative feedback (diminishing). Detecting, understanding, and accurately quantifying climate feedbacks have been the focus

of a great deal of research by scientists unraveling the complexities of Earth's climate.

2.4 Greenhouse Gases Effect

The sun, as the dominant thermal energy source, radiates energy at very short wavelengths. One third of the energy emitted by the sun gets reflected back to the earth without losing any of its portions. However, the remaining two-thirds of the energy is absorbed by the surface. In order to balance the absorbed incoming energy, intuitively enough, the Earth must, on average, radiate the same amount of energy back to space. Due to the fact that the Earth is much colder than the Sun, the radiation from the Earth's surface happens with longer wavelengths than that of the Sun. Much of this thermal radiation emitted by the land and ocean are absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is called the greenhouse effect. As a result, this warms the surface of the planet. Without the greenhouse effect, the temperature of the Earth would have been much colder than the freezing point of water. Thus, natural greenhouse makes Earth livable. However, the problem arises when things go beyond natural. Human activities, such as burning of fossil fuels and clearing of forests, have largely intensified the greenhouse effect, causing the global warming. Figure 2.2 shows a schematic for an idealized model of the natural greenhouse effect [3].

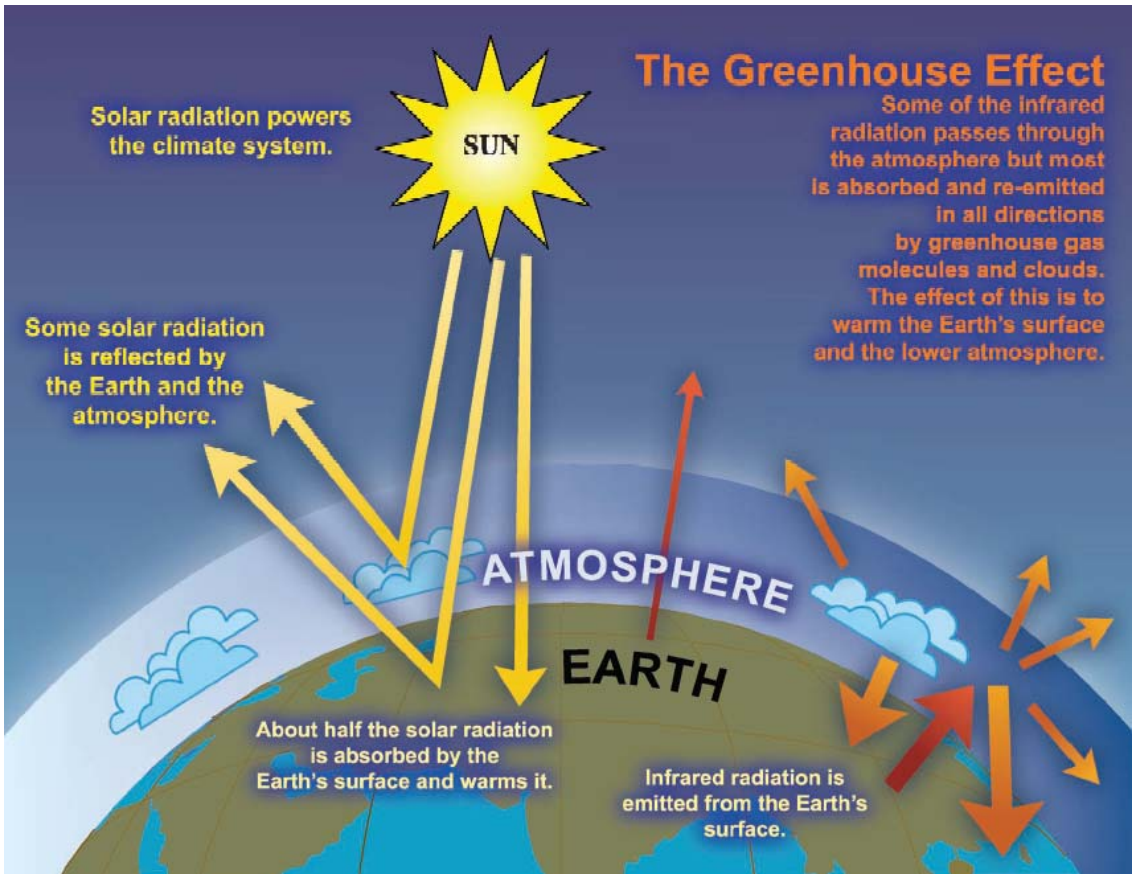

Figure 2.2. An idealized Model of Greenhouse Effect [3]

Scientists have known about the greenhouse effect since 1824, when Joseph Fourier calculated that the Earth would be much colder if it had no atmosphere. This greenhouse effect is what keeps the Earth's climate livable. Without it, the Earth's surface would be an average of about 60 degrees Fahrenheit cooler. In 1895, the Swedish chemist Svante Arrhenius discovered that humans could enhance the greenhouse effect by making carbon dioxide, a greenhouse gas. He kicked off 100 years of climate research that has given a sophisticated understanding of global warming. Levels of greenhouse gases (GHGs) have gone up and down over the Earth's history, but they have been fairly constant for the past few thousand years. Global average temperatures have stayed fairly constant over that time as well, until recently. Through the

burning of fossil fuels and other (GHG) emissions, humans are enhancing the greenhouse effect and warming Earth.

Scientists often use the term "climate change" instead of global warming. This is because as the Earth's average temperature climbs, winds and ocean currents move heat around the globe in ways that can cool some areas, warm others, and change the amount of rain and snow falling. As a result, the climate changes differently in different areas.

The dominant gases that make up the composition of the atmosphere are nitrogen comprising 78% and oxygen comprising 21% of the dry atmosphere composition. Despite their large composition percentages, they have no greenhouse effect. The main contributors to greenhouse effect are molecules that are more complex and much less common. Water vapor being the most important greenhouse gas causes 36 – 70% of the greenhouse effect (not including clouds). Carbon dioxide (CO_2) is the second important greenhouse gas that causes 9 – 26%. Methane (CH_4) causes 4 – 9%, ozone 3 – 7%. Some others naturally occurring gases contribute very small fractions of greenhouse gases effect; one of these nitrous oxide (N_2O), is increasing in concentration owing to human activity such as agriculture. [4]

The atmospheric concentrations of CO_2 and CH_4 have increased by 31% and 149% respectively since the beginning of the industrial revolution in the mid-1700s. These levels are considerably higher than at any time during the last 650,000 years, the period for which reliable data has been extracted from ice cores. From less direct geological evidence it is believed that CO_2 values this high were last attained 20 million years ago. Fossil fuel burning has produced about three-quarters of the increase in CO_2 from human activity over the past 20 years. Most of the rest is due to land-use change, in particular deforestation. [4]

The present atmospheric concentration of CO_2 is about 383 parts per million (ppm) by volume. Future CO_2 levels are expected to rise due to ongoing burning of fossil fuels and land-use change. The rate of rise will depend on uncertain economic, sociological, technological, and natural developments, but may be ultimately limited by the availability of fossil fuels. The Intergovernmental Panel on Climate Change (IPCC) special report on emissions scenarios gives a wide range of future CO_2 scenarios, ranging from 541 to 970 ppm by the year 2100. Fossil fuel reserves are sufficient to reach this level and continue emissions past 2100, if coal, tar sands or methane clathrate are extensively used. [4]

Figure 2.3 below represents a graphical representation of the atmospheric CO_2 concentration measured in a 50 year interval. The curve in the graph is known as the Keeling curve and is an essential piece of evidence of the man-made increases in greenhouse gases that are believed to be the cause of global warming (as a side note, the Keeling curve was named after Charles Keeling who was the first person to make frequent regular measurements of the atmospheric (CO_2) concentration). [4]

The graph shows the rapid change of CO_2 concentration during the indicated time period. From the graph, two patterns could be observed; the red curve shows the average monthly concentrations, and blue curve is a moving 12 month average that represents an annual fluctuation in CO_2 levels. These fluctuations could be attributed to the seasonal variations in carbon dioxide uptake by land plants. Since many more forests are concentrated in the Northern Hemisphere, more carbon dioxide is removed from the atmosphere during Northern Hemisphere summer than Southern Hemisphere summer. [4]

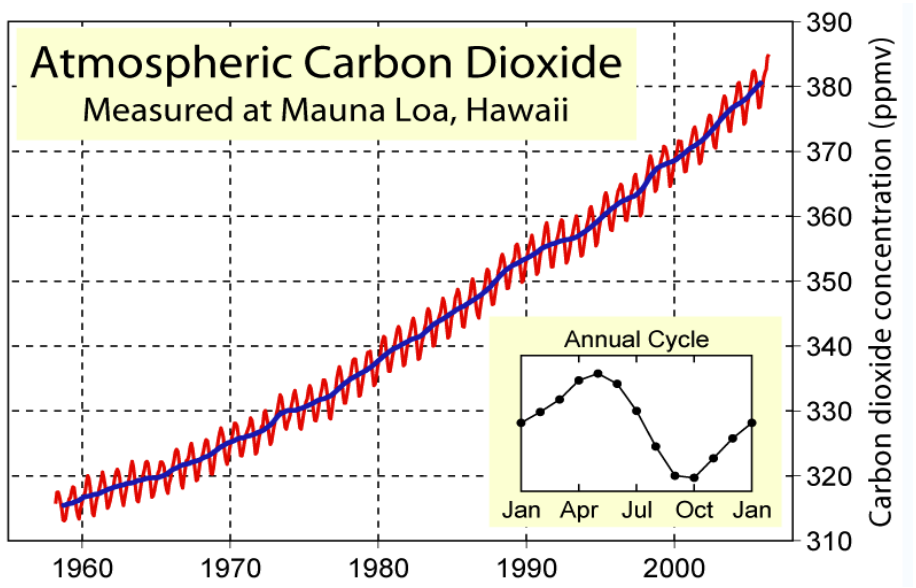

Figure 2.3 Keeling Curve [5]

2.5 Human Activities Contribution to Climate Change

Human activities results in emissions of four principal greenhouse gases: CO_2, methane CH_4, nitrous oxide N_2O, and the halocarbons (a group of gases containing fluorine, chlorine and bromine). These gases accumulate in the atmosphere, causing concentrations to increase with time. Significant increases in all of these gases have occurred in the industrial era. Figure 2.4 demonstrates how the greenhouse gases have been changing over the years.

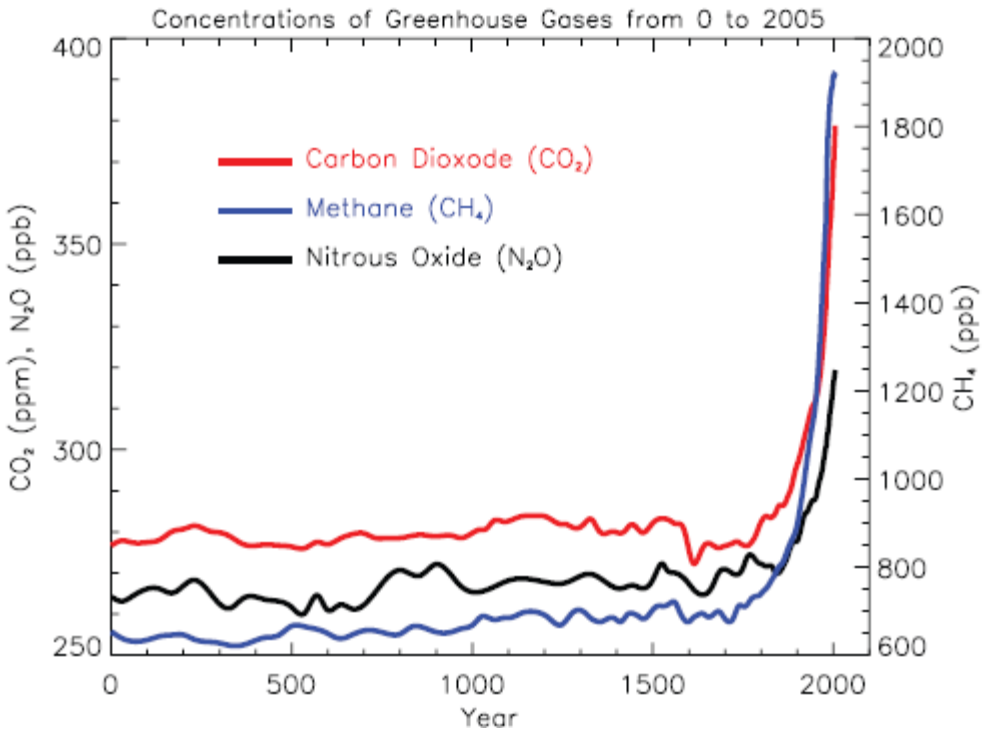

Figure 2.4 Greenhouse Gases Changes [7]

All of these increases are attributed to human activities.

1) CO_2 has increased from fossil fuel use in transportation, building heating and cooling and the manufacture of cement and other goods. Deforestation releases CO_2 and reduces its uptake by plants. CO_2 is also released in natural processes such as the decay of plant matter.
2) Methane has increased as a result of human activities related to agriculture, natural gas distribution and landfills. Methane is also released from natural processes that occur, for example, in wetlands. Methane concentrations are not currently increasing in the atmosphere because growth rates decreased over the last two decades.
3) Nitrous oxide is also emitted by human activities such as fertilizer use and fossil fuel burning. Natural processes in soils and the oceans also release N_2O.

4) Halocarbon gas concentrations have increased primarily due to human activities. Natural processes are also a small source. Principle halocarbons include the chlorofluorocarbons (e.g., CFC-11 and CFC-12), which were used extensively as refrigeration agents and in other industrial processes before their presence in the atmosphere was found to cause stratospheric ozone depletion. The abundance of chlorofluorocarbon gases is decreasing as a result of international regulations designed to protect the ozone layer.
5) Ozone is a greenhouse gas that is continually produced and destroyed in the atmosphere by chemical reactions. In the troposphere, human activities have increased ozone through the release of gases such as carbon monoxide, hydrocarbons and nitrogen oxide, which chemically react to produce ozone. As mentioned above, halocarbons released by human activities destroy ozone in the stratosphere and have caused the ozone hole over Antarctica.
6) Water vapor is the most abundant and important greenhouse gas in the atmosphere. However, human activities have only a small direct influence on the amount of atmospheric water vapor. Indirectly, humans have the potential to affect water vapor substantially by changing climate. For example, a warmer atmosphere contains more water vapor. Human activities also influence water vapor through CH_4 emissions, because CH_4 undergoes chemical destruction in the stratosphere, producing a small amount of water vapor.
7) Aerosols are small particles present in the atmosphere with widely varying size, concentration and chemical composition. Some aerosols are emitted directly into the atmosphere while others are formed from emitted compounds. Aerosols contain both naturally occurring

compounds and those emitted as a result of human activities. Fossil fuel and biomass burning have increased aerosols containing sulphure compounds, organic compounds and black carbon (soot). Human activities such as surface mining and industrial processes have increased dust in the atmosphere. Natural aerosols include mineral dust released from the surface, sea salt aerosols, biogenic emissions from the land and oceans and sulphate and dust aerosols produced by volcanic eruptions.

The differences in radiative forcing estimates between the present day and the start of the industrial era for solar irradiance changes and volcanoes are both very small compared to the differences in radiative forcing estimated to have resulted from human activities. As a result, in today's atmosphere, the radiative forcing from human activities is much more important for current and future climate change than the estimated radiative forcing from changes in natural processes. [5]

2.6 International acts in global warming

- World Meteorological Organization (WMO): The World Meteorological Organization is an intergovernmental organization with a membership of 188 Member States and Territories. It originated from the International Meteorological Organization (IMO), which was founded in 1873. Established in 1950, WMO became the specialized agency of the United Nations for meteorology (weather and climate)
- United Nations Environment Programme (UNEP): The United Nations Environment Programme (UNEP) was created in 1972 in order to initiate and catalyzes environmental action and awareness at all levels of society

worldwide, following the United Nations Conference on the Human Environment held in Stockholm.

- Intergovernmental Panel on Climate Change (IPCC): The Intergovernmental Panel on Climate Change is a scientific body tasked to evaluate the risk of climate change caused by human activity. The panel was established in 1988 by WMO and UNEP. The IPCC has been the main contributor to the global warming as far as studies and analyses are concernced. The IPCC does not carry out research, nor does it monitor climate or related phenomena. The main activity of the IPCC is publishing special reports on topics relevant to the implementation of the UN Framework Convection on Climate Change (UNFCCC). (The UNFCCC is an international treaty that acknowledges the possibility of harmful climate change; implementation of the UNFCCC led eventually to the Kyoto Protocol.) A detailed discussion about the IPCC main roles as well as its working groups is followed in a later section. [6]

The main activity of the IPCC, as mentioned previously, is to provide in regular intervals Assessment Reports of the state of knowledge on climate change. The latest one is "**Climate Change 2007**", the Fourth IPCC Assessment Report that has three working groups and a task force;

- The IPCC Working Group I (WG1):

It assesses the physical scientific aspects of the climate system and climate change. Its latest report "Climate Change 2007 - The Physical Science Basis" was launched on 2 February 2007 in Paris. The report includes information on changes in greenhouse gases and aerosols in the atmosphere and the extent to which they affect climate. It provides details of recent changes in air, land and ocean temperatures, rainfall, glaciers and ice sheets and considers a large amount of new satellite and other data that

have not been assessed previously. A paleoclimatic perspective considers the Earth's past cold and warm periods and the understanding of climate processes that can be gained from these. New information on feedbacks arising from the interaction of climate change with the biosphere and geochemistry is also considered. The most recent climate models are evaluated in detail, as is their use to explain observed climate change in terms of different driving factors. Projections of future climate change using climate models are considered broadly and cover near term climate change, the degree to which this is 'committed' due to past increases in greenhouse gases, and a range of potential longer-term climate changes. Patterns of future climate change are considered both globally and regionally. [7]

- The IPCC Working Group II (WG2):

The IPCC Working Group II assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it. Its latest report "Climate Change 2007 - Impacts, Adaptation and Vulnerability" was launched on 6 April 2007 in Paris. The report assesses the latest scientific, environmental and socio-economic literature on "Impacts, Adaptation and Vulnerability". It provides a comprehensive analysis of how climate change is affecting natural and human systems, what the impacts will be in the future and how far adaptation and mitigation can reduce these impacts. It also takes into consideration the inter-relationship between adaptation and mitigation, and the relationship between climate change and sustainable development. The report contains chapters on specific systems and sectors (water resources; ecosystems; food & forests; coastal systems; industry; human health) and

regions (Africa; Asia; Australia & New Zealand; Europe; Latin America; North America; Polar Regions; Small Islands).[8]

- The IPCC Working Group III (WG3):

The IPCC WG3 assesses options for mitigating climate change through limiting or preventing greenhouse gas emissions and enhancing activities that remove them from the atmosphere. Its latest report, "Climate Change 2007 - Mitigation of Climate Change" was launched on 4 May 2007 in Bangkok. After describing the GHGs emission trends, the report analyses mitigation options for the main economic sectors in the near-term; between now and 2030, providing an in-depth analyses of the costs and benefits of different approaches. It further evaluates long-term mitigation strategies for various stabilization levels, paying special attention to implications of different short-term strategies for achieving long-term goals. Cross-sectorial matters such as synergies, co-benefits and trade-offs are taken into consideration. The report, oriented at assessing the solutions to respond to climate change, considers the policy measures and instruments available to governments and industries to mitigate climate change. It also addresses the significant relationship between mitigation and sustainable development. [9]

- The Task Force on National Greenhouse Gas Inventories (TFI) :

It was established by the IPCC to oversee the IPCC National Greenhouse Gas Inventories Programme (IPCC-NGGIP). It latest Report is called “2006 IPCC Guidelines for National Greenhouse Gas Inventories”.

- Other IPCC activities:

Task Group on Data and Scenario Support for Impacts and Climate Analysis (TGICA). The Task Group on Data and Scenario Support for Impacts and Climate Analysis (TGICA) aims to facilitate wide availability

of climate change related data and scenarios for climate analysis and impacts, adaptation, vulnerability, and mitigation research. The TGICA does not develop itself any emission, climate, or other types of scenarios, nor does it make any decisions regarding the choice of scenarios in the preparation of the IPCC reports. It does not undertake any modeling or research. The Task Group, previously called Task Group on Scenarios for Climate and Impacts Assessment (TGCIA), was established to facilitate co-operation between the climate modeling and climate impacts assessment communities. One of the main activities of the TGICA is the coordination and oversight of the IPCC Data Distribution Centre (DDC), which provides consistent data sets such as results from climate change experiments, i.e. data from global climate models (GCMs) produced by different modeling centers, observed climate datasets, observed environmental data including concentrations of CO2 and other greenhouse gases, and socio-economic scenario information. The information available on the DDC is accompanied by documentation and guidance material on how the climate scenarios and baseline data can be used in impacts and adaptation assessments. The Task Group is composed of experts in climatology; climate modeling; physical, social, and economic impacts; adaptation; emissions scenarios; and integrated assessment. [10]

2.7 Kyoto Protocol

The Kyoto Protocol is an agreement made under the United Nations Framework Convection on Climate Change (UNFCCC). Countries that ratify this protocol commit to reduce their emissions of CO_2 and five other greenhouse gases, or engage in emissions trading if they maintain or increase emissions of these gases.

The Kyoto Protocol now covers more than 170 countries globally and more than 60% of countries in terms of global greenhouse gas emissions. As of December 2007, the US and Kazakhstan are the only signatory nations not to have ratified the act. This treaty expires in 2012, and international talks began in May 2007 on a future treaty to succeed the current one.

At its heart, the Kyoto Protocol establishes the following principles:

1. Kyoto is underwritten by governments and is governed by global legislation enacted under the UN's agencies.
2. Governments are separated into two general categories: developed countries, referred to as Annex I countries (who have accepted greenhouse gas emission reduction obligations and must submit an annual greenhouse gas inventory); and developing countries, referred to as Non-Annex I countries (who have no greenhouse gas emission reduction obligations but may participate in the Clean Development Mechanism).
3. Any Annex I country that fails to meet its Kyoto obligation will be penalized by having to submit 1.3 emission allowances in a second commitment period for every ton of greenhouse gas emissions they exceed their cap in the first commitment period (i.e., 2008-2012);
4. As of January 2008, and running through 2012, Annex I countries have to reduce their greenhouse gas emissions by a collective average of 5% below their 1990 levels (for many countries, such as the EU member states, this corresponds to some 15% below their expected greenhouse gas emissions in 2008).
5. Kyoto includes "flexible mechanisms" which allow Annex I economies to meet their greenhouse gas emission limitation by purchasing GHG emission reductions from elsewhere. [11]

2.8 Carbon Emissions Climbing

Though economic growth slowed throughout much of the world during 2001, world carbon emissions from burning fossil fuels continued to increase, exceeding 6.5 billion tons. As a result of the consistent growth of emissions, the atmospheric concentration of CO_2 has increased from the preindustrial level of 280 parts per million (ppm) to today's 370 ppm, a 32% increase. In the last 20 years, the atmospheric concentration of CO_2 has increased with a rate of 1.5 ppm a year that has not been reached before.

In 1950, carbon emissions reached to 1.6 billion tons. By 1977, the rate has tripled to 4.9 billion tons. In 2000, carbon emissions approached 6.5 billion tons, a quadrupling in just 50 years. Table 2.1 and Figure 2.6 represent a tabulated data for the carbon emissions from fossil fuel burning from 1950 until 2001 along with its accompanying graph respectively.

Year	Million Tons of Carbon	Year	Million Tons of Carbon
1950	1612	1976	4776
1951	1748	1977	4910
1952	1774	1978	4962
1953	1817	1979	5249
1954	1838	1980	5177
1955	2013	1981	5004
1956	2146	1982	4959
1957	2236	1983	4942
1958	2295	1984	5113
1959	2423	1985	5274
1960	2535	1986	5436
1961	2550	1987	5558
1962	2652	1988	5774
1963	2798	1989	5879
1964	2952	1990	5939
1965	3087	1991	6025
1966	3243	1992	5922
1967	3347	1993	5914
1968	3518	1994	6050
1969	3728	1995	6182
1970	3997	1996	6327
1971	4143	1997	6419
1972	4305	1998	6401
1973	4538	1999	6366
1974	4545	2000	6480
1975	4518	2001	6553

Table 2.1. Carbon Emissions from Fossil Fuel Burning [10]

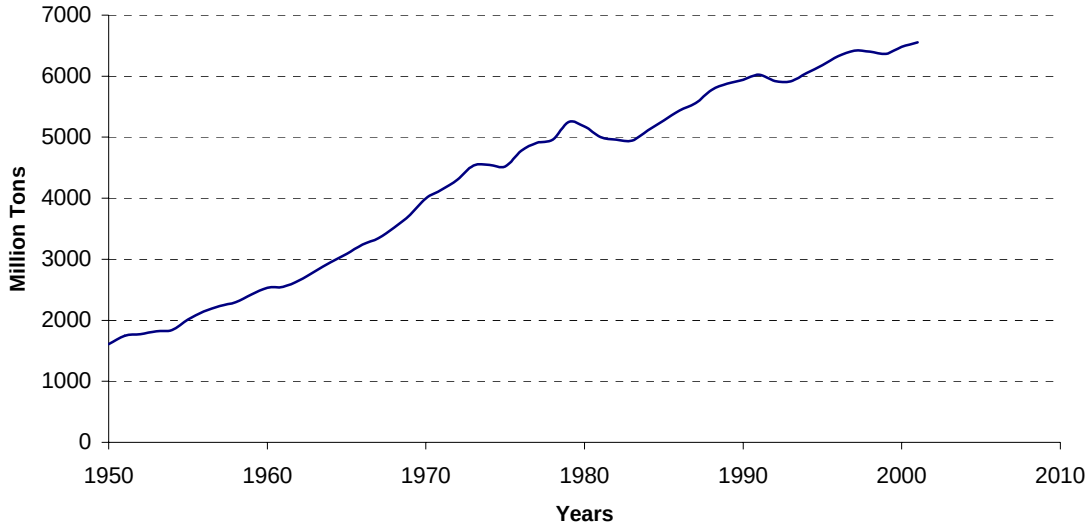

Figure 2.6 Carbon Emissions from Fossil Fuel [12]

Seventy five percent of emissions from human activities are due to the combustion of fossil fuels; the remaining 25% is caused by changes in land use, mainly deforestation. The consumption of Global energy is projected to rise 60% during the next 20 years. Coal use is expected to increase by 45%, oil consumption by 58% and natural gas by 93%, according to the U.S. Department of Energy. Since coal consumption has actually declined by 6% since its peak in 1996, however, there is reason to believe its use will either continue to decline or increase less than projected. However, even if coal consumption stays steady over the next 20 years, the current level of emissions from all fossil fuels is simply too high. The increasing use of fossil fuels will only exacerbate changes in global climate.

According to the IPCC, by 2100, the concentrations of CO_2 will be in the range of 650 to 970 ppm – more than double or triple preindustrial levels. As a consequence, the global average surface temperature will likely rise between 1.4 and 5.8^{o}C between 1990 and 2100, an unprecedented rate of increase.

Carbon emissions are produced by possibly four major sectors; electricity generation being responsible for the largest share contributing 42%. Transportation generates 24% of global emissions. Industrial processes account for 20%, and residential and commercial uses produce the remaining 14%. The United States contributes the largest share in producing carbon emissions with 24% of the global total. China is responsible for 14%, and Russia accounts for 6%. Japan and India are each responsible for 5% of world emissions.

As a result of the increasing carbon emissions, various policy measures have been introduced to resolve the issue. The most prominent is the Kyoto Protocol mentioned previously. However, to be enforced, 55 countries representing 55 percent of emissions from industrial and former Eastern bloc nations must ratify the treaty. As of early June 2002, 74 countries responsible for 35.8 percent of global GHG emissions have ratified the protocol, including Japan and all nations of the European Union. But with the United States and Australia refusing to ratify, the likelihood that it will enter into force is considerably diminished. Table 2.2 below is a list of the change in greenhouse gas emissions from 1990 to 2004 for some countries that are part of the climate change convention as reported by the United Nations.

Country	Change in greenhouse gas emissions (1990 - 2004) excluding LULUCF	Change in greenhouse gas emissions (1990 - 2004) excluding LULUCF	EU Assigned Objective for 2012	Treaty Obligation 2008 - 2012
Germany	-17%	-18.20%	-21%	-8%
Canada	+27%	+62.20%	N/A	-6%
Australia	+25%	+5.20%	N/A	+8%
Spain	+49%	+50.40%	+15%	-8%
United States	+16%	+21.10%	N/A	-7%*
Norway	+10%	-18.70%	N/A	+1%
New Zealand	+21%	+17.90%	N/A	0%
France	-0.80%	-6.10%	0%	-8%
Greece	+27%	+25.30%	+25%	-8%
Ireland	+23%	+22.70%	+13%	-8%
Japan	+6.50%	+5.20%	N/A	-6%
United Kingdom	-14%	-14.80%	-12.50%	-8%
Portugal	+41%	+28.90%	+27%	-8%
EU-15	-0.80%	-2.60%	N/A	-8%

Table 2.2. Change in Greenhouse Gas Emissions from 1990 to 2004 [10]

Comparing total greenhouse gas emissions in 2004 to 1990 levels, the US emissions were up by 16%, with irregular fluctuations from one year to another but a general trend to increase At the same time, the European Union group of 23 (EU-23) Nations had reduced their emissions by 5%. In addition, the EU-15 group of nations (a large subset of EU-23) reduced their emissions by 0.8% between 1990 and 2004, while emission rose 2.5% from 1999 to 2004. Part of the increases for some of the European Union countries is still in line with the treaty, being part of the cluster of countries implementation. As of the end of 2006, the United Kingdom and Sweden were the only EU countries on pace to meet their Kyoto emissions commitments by 2010. While United Nation statistics indicate that, as a group, the 36 Kyoto signatory countries can meet the 5% reduction target by 2012, most of the progress in greenhouse gas reduction has come from the stark decline in Eastern European countries' emissions after the fall of communism in the 1990s.

Since the US did not ratify the treaty, the emissions targets are not a treaty obligation. However, as an alternative, the United States passed an act called "Clear Skies" that requires a decline in carbon emissions per unit of economic output (known as carbon intensity), but not overall carbon emissions. The disadvantage of the proposal is that economic growth cannot be achieved without significant carbon emission increases; thus "Clear Skies" will not fundamentally alter the U.S. emissions trajectory. The U.S. economy has consistently improved its carbon intensity, yet emissions have continued to increase. According to the American Council for an Energy-Efficient Economy, the carbon intensity of the U.S. economy was cut by 17% between 1990 and 2000, yet total emissions increased during that time by 14% due to a 39% increase in economic activity.

The Kyoto Protocol, even if implemented, is only a first step. According to the IPCC, stabilizing atmospheric levels of CO_2 at 450 ppm would require

fossil fuel emissions to drop below 1990 levels within a few decades, and eventually to decline to a small fraction of current levels. Regardless of the ultimate fate of the Kyoto Protocol, other policy initiatives show promise. Decreasing or eliminating government subsidies to fossil fuels, which total $300 billion annually worldwide, can move the energy economy away from heavy reliance on carbon-intensive fossil fuels. Decreasing taxes on income while instituting or increasing carbon taxes would constructively align economic and environmental goals. Increasing funding for further research and development of clean energy technologies can also help move the world from a carbon-based and toward a hydrogen-based energy system. Finally, stabilizing human population sooner rather than later will help reduce future emissions. [12]

2.9 Global Warming Solutions

In this section, one addresses some proposed solutions to resolve the issue of global warming. The solutions to climate change could have a significant impact in the long run or in the short run. They are some limitations that might hinder the implications or the usage of such solutions. These limitations include, but not limited to, cost, economy, difficulty to implement, and results. The solutions explained in this section are using electricity end-use efficiency, other end-use efficiency, passenger vehicle and other transport efficiency, renewable technologies, and most importantly Carbon Capture and Storage (CCS). If we get started today one can tackle this problem and decrease the unpleasant outcomes that await us if we do nothing because the cost of inaction could be devastatingly high. [13]

2.9.1 Electricity end-use Efficiency

It has been repeatedly mentioned that CO_2 is one of the major greenhouse gases that causes an increase in global temperature. As previously noted, electricity generation is responsible for about 42% of CO_2 emission, the largest share. Therefore, to start off, using electricity end-use efficiency approach would be the first option to think when speaking about global warming solutions.

Worldwide, industry uses about 50% of all electricity and buildings consume almost as much (45%). Technologies to significantly improve electricity efficiency exist for virtually all buildings and industrial end-uses. For industry, the greatest savings in electricity can often be achieved by process changes that require less energy input to produce a final product rather than by retrofits of existing processes. Examples of some technologies for buildings include efficiency improvements for residential appliances, lighting, air conditioners, heating systems, and thermal integrity of building envelopes. In the United States, the average new refrigerator consumes half as much electricity as a comparable refrigerator purchased twenty years ago. In Japan, the efficiency improvement has been even greater (fourfold), primarily because the older refrigerators were much less efficient that U.S. models. The doubling of refrigerator efficiency in the United States was due to using foam instead of fiberglass insulation, thicker insulation, more efficient motors and compressors, and larger heat exchangers. [14]

2.9.2 Other end-use Efficiency

End use offers the greatest near-term potential for large increases in efficiency and avoids GHG emissions or net reductions in GHG emissions. Some of the technologies that could be implemented to improve other end-use

efficiency include solar water heating, geothermal heat pump and electro-technologies.

2.9.3 Passenger Vehicle and Other Transport Efficiency

The most efficient machines for converting energy to rotary motion are electric motors, as used in electric vehicles. However, electricity is not a primary energy source so the efficiency of the electricity production has also to be taken into account. Currently railway trains can be powered using electricity, delivered through an additional running rail, overhead catenary system or by onboard generators used in disel-electric locomotives as common on the UK rail network. Pollution produced from centralised generation of electricity is emitted at a distant power station, rather than "on site". Some railways, such as the French SNCF and Swiss federal railways derive most, if not 100% of their current, from hydroelectric or nuclear power stations, therefore atmospheric pollution from their rail networks is very low. This was reflected in a study by AEA Technology between a Eurostar train and airline journeys between London and Paris, which showed the trains on average emitting 10 times less CO_2, per passenger, than planes, helped in part by French nuclear generation which, however, creates its own radioactive waste which air flight does not. So only comparing CO_2 is misleading. This can be changed using more renewable sources for electric generation. [15]

2.9.4 Renewable Energy (Fuels)

The United States currently relies heavily on coal, oil, and natural gas for its energy. Fossil fuels are non-renewable, that is, they draw on finite resources that will eventually dwindle, becoming too expensive or too environmentally

damaging to retrieve. In contrast, renewable energy resources – such as wind and solar energy-are constantly replenished and will never run out.

Most renewable energy comes either directly or indirectly from the sun. Sunlight, or solar energy, can be used directly for heating and lighting homes and other building, for generating electricity, and for hot water heating, solar cooling, and a variety of commercial and industrial uses.

The sun's heat also drives the winds, whose energy is captured with wind turbines. Then, the winds and the sun's heat cause water to evaporate. When this water vapor turns into rain or snow and flows downhill into rivers or streams, its energy can be captured using hydroelectric power.

Along with the rain and snow, sunlight causes plants to grow. The organic matter that makes up those plants is known as biomass. Biomass can be used to produce electricity, transportation fuels, or chemicals. The use of biomass for any of these purposes is called bio-energy. Hydrogen also can be found in many organic compounds, as well as water. It's the most abundant element on the Earth. But it does not occur naturally as a gas. It is always combined with other elements, such as with oxygen to make water. Once separated from another element, hydrogen can be burned as a fuel or converted into electricity. [16]

2.9.5 Carbon capture and storage (CCS)

CCS is an approach to mitigate global warming by capturing CO_2 from large point sources such as fossil fuel power plants and storing it instead of releasing it into the atmosphere. Technology for large scale capture of CO_2 is already commercially available and fairly well developed. CCS applied to a modern conventional power plant could reduce CO_2 emissions to the atmosphere by approximately 80-90% compared to a plant without CCS. Capturing and compressing CO_2 requires much energy and would increase the fuel needs of a

plant with CCS by about 11-40%. These and other system costs are estimated to increase the cost of energy from a new power plant with CCS by 21-91%. These estimates apply to purpose-built plants near a storage location: applying the technology to preexisting plants far from a storage location will be more expensive.

Storage of the CO_2 is envisaged either in deep geological formations, or in the form of mineral carbonate. In the case of deep ocean storage, there is a risk of greatly increasing the problem of ocean acidification, a problem that also stems from the excess of carbon dioxide already in the atmosphere and oceans. Geological formations are currently considered the most promising sequestration sites, and these are estimated to have a storage capacity of at least 2000 Gt (gigatonne) CO_2 (currently, 30 Gt per year of CO_2 is emitted due to human activities). IPCC estimates that the economic potential of CCS could be between 10% and 55% of the total carbon mitigation effort until year 2100. [17]

2.10 The Cement Industry and Global Warming

Greenhouse gas emissions, especially carbon dioxide (CO_2) are mainly associated with fuel combustion and with the de-carbonation of limestone, which in its pure form is 44 percent CO_2 by weight, for these the cement industry is an important contributor to global warming.

The cement industry is faced with the challenge of reducing the large amounts of carbon dioxide emitted during the production of ordinary Portland cement. Although improvements can be made to the existing process, these would not bring about significant reductions in carbon dioxide.

2.10.1 Portland Cement Production Process

The cement manufacturing process involves four distinct stages, and these are outlined below:

Step 1 - Quarrying

The raw material for cement manufacture is a rock mixture which is about 80% limestone (which is rich in $CaCO_3$) and 20% clay or shale (a source of silica, alumina and Fe_2O_3).

These are quarried and stored separately. The lime and silica provide the main strength of the cement, while the iron reduces the reaction temperature and gives the cement its characteristic grey color.

Step 2 - Raw material preparation

The steps involved here depend on the process used. There are two main cement Manufacturing processes currently used: the dry process and the wet process. The dry process uses more energy in grinding but less in the kiln and the wet process has lower overheads than the dry process. The two processes are discussed separately below.

- The dry process:

The quarried clay and limestone are crushed separately until nothing bigger than a tennis ball remains. Samples of both rocks are then sent off to the laboratory for mineral analysis. If necessary, minerals are then added to either the clay or the limestone to ensure that the correct amounts of aluminum, iron etc. is present. The clay and limestone are then fed together into a mill where the rock is ground until more than 85% of the material is less than 90μm in diameter.

- The wet process:

The clay is mixed to a paste in a wash mill - a tank in which the clay is pulverized in the Presence of water. Crushed lime is then added and the whole mixture further ground. Any material which is too coarse is extracted and

reground. The slurry is then tested to ensure that it contains the correct balance of minerals, and any extra ingredients blended in as necessary.

Step 3 - Clinkering

This is the step which is characteristic of Portland cement. The finely ground material is dried, heated (to enable the sintering reactions to take place) and then cooled down again. While it is being heated various chemical reactions take place to form the major mineral constituents of Portland cement.

The powder from the dry process doesn't contain much moisture, so can be dried in a pre-heater tower. As it falls through the tower (which takes 30 seconds) it is heated from 70 to 800oC. The moisture evaporates, up to 20% of the de-carbonation (loss of CO_2) occurs and some intermediate phases such as $CaO•Al_2O_3$ begin to appear. The mixture is then fed into the kiln.

The slurry from the wet process contains too much moisture to be successfully dried in a pre-heater tower. Instead, the slurry is fed directly into the kiln where it is formed into dry balls by the heat and rotation of the kiln. Because of this extra role of the kiln, wet process kilns are generally longer than dry process kilns. The kilns used in both processes are inclined on a shallow angle and lined with heat-resistant bricks.

Step 4 - Cement milling

To produce the final product the clinker is mixed with gypsum ($CaSO_4•2H_2O$), which is added as a set retarded, and ground for approximately 30 minutes in large tube mills. The cement flows from the inlet to the outlet of the mill (a rotating chamber), being first ground with 60 mm then 30 mm diameter steel balls. The first grinding breaks up the material and the second grind it to a fine powder. The amount of grinding is governed by the volume of cement fed into the mill: the greater the volume the coarser the grind. This has practical limits, with too much cement clogging up the mill and not enough

actually increasing the particle size. The particle size is measured by laser diffraction analysis, and the quantity of material entering the mill adjusted accordingly. Over time the charge (steel grinding balls) wear out, so when they reach a certain size they fall through a sieve and then are replaced. The rotating mill generates significant quantities of energy and water is added to both the inlet and outlet ends of the mill to cool the product and the mill itself. [18]

2.10.2 Raw materials

Cement is a manufactured product made by blending different raw materials and firing them at a high temperature in order to achieve prices chemicals proportion of lime, silica, alumina and iron in the finished product, known as cement clinker. Cement is therefore essentially a mixture of calcium silicates and smaller amounts of calcium aluminates that react with water and cause the cement to set.

The requirement for calcium is met by using high calcium limestone and clay, mudstone or shale as the source of most of the silica and alumina. Finished cement is produced by finely grinding together around 95% clinker with 5% gypsum which helps to retard the setting time of cement.

The quality of cement clinker is directly related to the chemistry of raw materials used around 80-90% of raw material for the kiln feed is limestone. Clayey raw material accounts for between 10-15%, although the precise amount will vary. Magnesium carbonate, which may be present in limestone, is the main undesirable impurity. The level of magnesia (MgO) in the clinker should not exceed 5% and many producers favor a maximum of 3%, this rules out dolomite limestone for cement manufacture. Other deleterious materials include excessive alkalis (sodium oxide, Na_2O or soda and potassium oxide, K_2O) witch would be

unacceptable because of durability problems with concrete (due to reaction of alkalis with some siliceous aggregates to form a swelling get).

Portland cement is the most widely produced cement. The term 'Portland cement' was created because of the presumed resemblance of the set material to Portland stone, the well-known natural building stone. Other varieties include rapid hardening, low heat, sulfate resisting, and low-alkali cements. In addition, blended cements are produced by finely grinding Portland cement clinker with other constituents, such as blast furnace slag, natural Pozzlanas, silica fume metakaoline, siliceous fly ash, calcareous fly ash, limestone fines and shale. [19]

2.10.3 Fuels

The most commonly used fuel in the cement industry is coal (black coal and lignite); however the lower cost of petroleum coke (pet–coke) has resulted in increased use of this fuel type. Coal and pet–coke generate higher emissions of greenhouse gases (GHG) than fuel oil and natural gas. In addition, high sulfur content in the fuel (characteristic of petcock) may create problems, including mainly sulfur buildup on rings in the kiln. Use of waste fuel as an alternative to traditional fuel is increasingly common in the cement industry, however related air emission concerns should be considered. Pollution abatement measures may be necessary to ensure that no toxic emissions are generated from the firing of waste in cements kilns. Adequate monitoring should be conducted when waste fuels are being fired at cement plants. [20]

2.10.4 Kiln

In industrialized countries the predominant type of kiln used is the rotary kiln, which basically consists of a tube with a diameter of up to 6 meters. The tube is installed at an angle of 3-4^{O}, and rotates about twice a minute to improve

homogenization. Raw materials are fed to the top and move towards the flame at the bottom of the kiln. The length of short kilns can be up to 65-120m. Long kilns can get as large as 200m (Hendricks et al., 1998). The kiln can be equipped with a pre-heater, in which the raw meal is preheated with waste heat from the kiln.

For new plants and major upgrades, good international practice for the production of cement clinker involves the use of a dry process kiln with multistage preheating and precalcination (PHP\ kilns). PHP kilns are the most common kiln used in the cement manufacturing industry. They have the lowest heat consumption (due to the high heat recovery from kiln gas in the cyclones, and the low kiln heat losses), and no water to evaporate (compared to wet kiln which uses slurry), while also offering the highest Production capacity. [20]

The aim of the zone enlargement is the extension of the material's residence decrease the gas velocity for better heat transfer from the kiln gas to the material. However, this causes different transportation times resulting in irregular material passage, thus impairing the kiln's operation.

Types of rotary kilns:

a. Straight rotary kilns

b. Rotary kiln with enlarged burning zone

c. Rotary kiln with enlarged calcining zone

d. Rotary kiln with enlarged calcining and burning zone

e. Rotary kiln with enlarged drying calcining and burning zone (wet process kiln)

f. Rotary kiln with enlarged drying or preheating zone (long dry process or wet process kiln). [21]

2.10.5 Pre-heater

New developments in precalciners and preheated is important for reducing carbon dioxide in combustion process. The pre-heater must achieve a transfer of heat from the pyroprocessing system exhaust gases to the incoming raw meal in preparation for the energy intensive decarbonation process to occur in the calciner With the dynamic environmental regulations constantly becoming more and stricter, equipment suppliers must develop combustion methods to keep pace with the newly imposed limits. Multi-staged combustion, at least for now, offers a relatively low cost approach to meeting the accepted emission

A type of pre-heater that is especially suitable for the dry kiln is the suspension pre-heater, consisting of multiple preheating stages. The higher the number of stages is, the larger the energy savings compared to a kiln without pre-heater. An option to further reduce energy consumption is the application of a precalciner in between the kiln and the pre-heater. The precalciner basically consists of a separate burner chamber is dissociated before it enters the kiln. [22]

The preheated tower dominates the landscape, rising more than 200 feet. The tower supports a series of vertical cyclone chambers through which the raw meal passes one its way to the kiln. Hot exit gases rising from the kiln heat the material as it swirls through the cyclones.

Some pre-heaters contain a furnace or precalciner at the bottom of the pre-heater tower just before the kiln. Material from the last stage cyclone enters the precalciner along with hot combustion air and fuel. As much as 95% of calcinations-the removal of carbon dioxide from raw materials-takes place here.

From the pre-heater, the material now enters the kiln at the upper or feed end. It slides and tumbles down the kiln through progressively hotter zones toward the flame. Remaining carbon dioxide in the raw materials is driven off, and the intense heat triggers other chemical reactions.

Low presser-loss suspension pre-heater

This suspension pre-heater uses a low pressure-loss cyclone developed to reduce the temperature of the waste heat, and the energy required for firing by converting NSP four-stage cyclones to five or six-stage

Conversion of a suspension pre-heater to a five-stage cyclone

Many NSP cement plants have a four-stage configuration. In this case, the waste heat from the cement plant is recovered for waste heat power generation. With a five-stage cyclone. [21]

3. Materials & Methods

3.1 Mathematical Modeling of Global Climate:

3.1.1 A Simple Global Temperature:

In order to predict future impacts of anthropogenic changes in the environment, there is a need to develop mathematical models that explain the past. However, it is a difficult task to come up with a good mathematical model that demonstrates fully the climate change phenomenon and predicts the impacts of changes in key environmental parameters. Such mathematical models range between simple to complex calculations, three dimensional general circulation models (GCMs), which attempt to predict climate on original, seasonal, and annual basis. The most sophisticated to these models can take weeks to run on a supercomputer.

The simplest starting point for modeling climate begins with models that focus on factors influencing the single variable temperature. Obviously, other factors such as precipitation patterns, winds and storms, ocean currents, soil moisture, sea ice, glacial cover, and so forth, are exceedingly important, but they are more difficult to approach with a simple model. For simplicity, the global temperature model that will be obtained in this section is not a function of location or time.

The average annual intensity of heat that the sun provides to the Earth, *S*, was measured to be 1370 W/m^2. A simple way to calculate the total rate at which energy hits the Earth is to note that all of the flux passing through a "hoop" having a radius equal to that of the Earth, and placed normal to the incoming radiation, strikes the Earth's surface. Therefore, Equation 3.1 gives the total rate at which solar energy strikes the earth

$$Rate = S\pi R^2 \qquad (3.1)$$

Where S is the solar constant taken to be 1370 W/m^2, R is the radius of the Earth given in meters. Out of the total of the solar energy received from the Sun, some of it is reflected back into space (albedo), and since the reflection is assumed to be complete, this reflected fraction of the energy does not contribute to the heating of the Earth or its atmosphere. The fraction of the albedo is now estimated to be 31 percent. What is not reflected is assumed to be absorbed. Equations 3.2 and 3.3 illustrate how the reflected and absorbed energies are calculated respectively,

$$\text{Energy Reflected} = S\pi R^2 \alpha \qquad (3.2)$$

$$\text{Energy Absorbed} = S\pi R^2 (1-\alpha) \qquad (3.3)$$

Where α is the Earth's albedo.

We know that there is no heat transfer from the Earth to space by conduction or convection; so, the only way for the Earth to get rid of energy is by radiation. To get a complete picture of the energy balance equation, we need to consider the rate at which the Earth sends energy back to space. For simplicity, couple of assumptions were made to carry on deriving the mathematical model for the energy balance equation; these assumptions are;

- The Earth is modeled as a blackbody (emissivity = 1).
- The temperature is isothermal (uniform throughout).
- Steady-state condition (Earth's temperature is not changing with time).

For a blackbody with surface area A and absolute temperature T_e, the total rate at which radiant energy is emitted is given by the *Stefan-Boltzmann law of radiation*. The law states that the rate at which an object radiates energy is proportional to its surface area times its absolute temperature raised to the fourth power, Equation 3.4.

$$\text{E} = \sigma 4\pi R^2 T_e^4 \qquad (3.4)$$

Where,

E = total blackbody emission rate (W)

σ = the Stefan-Boltzmann constant = 5.67×10^{-8} W/m^2 K^4

T_e = absolute temperature (K)

At steady state, using Equations 3.3 and 3.4 to produce 3.5.

$$S\pi R^2(1-\alpha) = \sigma 4\pi R^2 T_e^4 \qquad (3.5)$$

Solving Equation 3.5 for T_e

$$T_e = \left[\frac{S(1-\alpha)}{4\sigma}\right]^{1/4} \qquad (3.6)$$

Substituting appropriate values into Equation 3.6 yields the following absolute temperature

$$T_e = \left[\frac{1370 \text{ W/m}^2(1-0.31)}{4 \times 5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4}\right]^{1/4} = 254 \text{ K} = -19 \text{ }^{\circ}\text{C}$$

The actual temperature of the Earth should be 288 K. However, the mathematical model presented above says that the temperature of the Earth is 254K. Calculating the percentage error from Equation 3.7 yields the following

$$\text{Percentage Error} = \frac{\text{Actual - Model}}{\text{Actual}} \times 100 = \frac{288-254}{288} \times 100 = 12\% \qquad (3.7)$$

There is a need to find an explanation for why the Earth is fortunately not that cold. The key factor that makes the theoretical model differ so much from reality is that it does not account for interactions between the atmosphere and the radiation that is emitted from the Earth's surface. That is, it does not include the greenhouse effect. Thus, since the actual temperature of the Earth is 288 K and the temperature obtained from Equation 3.6 is 254 K, there for the greenhouse effect adds 34^{o}C of warming to the surface of the Earth.

3.1.2 Global Energy Balance for Climate Change:

To build on our mathematical model, let us consider the Earth, its atmosphere, and out space as three separate regions. Normalizing energy flows between these regions by expressing them in terms of rates per unit of surface area of the Earth. Therefore, normalizing Equation 3.1 yields the following

$$\frac{\text{Incoming Solar Radiation}}{\text{Surface Area of Earth}} = \frac{S\pi R^2}{4\pi R^2} = \frac{S}{4} = 342\,\text{W/m}^2 \qquad (3.8)$$

Since the albedo is 31 percent, the amount of incoming radiation reflected back into space per square meter of the Earth's surface is

$$\frac{\text{Solar Energy Reflected}}{\text{Surface Area of Earth}} = \frac{S\pi R^2\alpha}{4\pi R^2} = \frac{S}{4}\alpha \qquad (3.9)$$

$$= 342\,\text{W/m}^2 \times 0.31 = 107\,\text{W/m}^2$$

Of this 107 W/m^2, it is estimated that 77 W/m^2 are reflected off the atmosphere itself, while the remaining 30 W/m^2 are reflected off the Earth's surface. The solar radiation that is not reflected is absorbed by the Earth and its atmosphere. Calling that absorbed energy Q_{abs} gives

$$Q_{abs} = \frac{S\pi R^2(1-\alpha)}{4\pi R^2} = \frac{S}{4}(1-\alpha) \qquad (3.10)$$

$$= 342\ \text{W/m}^2 \times (1-0.31) = 235\,\text{W/m}^2$$

Of that 235 W/m^2, 67 W/m^2 are absorbed by the atmosphere and the remaining 168 W/m^2 are absorbed by the surface of the Earth.

Assuming that the global temperatures are independent on time, i.e. they are unchanging with time, hence, the rate at which the Earth and its atmosphere receive energy from space must be equal to the rate at which energy is being returned to space. The 107 W/m^2 of reflected energy is already balanced; that is, 107 W/m^2 hits the earth/atmosphere and 107 W/m^2 is reflected back into space so this energy can be can ignored for now. The Earth and its atmosphere absorb the remaining 235 W/m^2, so the same amount must be radiated back into space. By

assuming the temperature of the surface is actually 254K as found by the model, the Earth would radiate 235 W/m^2, which is just enough to balance the incoming energy. It is known, however, that greenhouse gases would absorb most of the outgoing 235 W/m^2, so the required energy would not realize. Therefore, to force enough energy through the atmosphere to create necessary balance, the temperature of the Earth's surface must be higher than 254K.

If one treats the Earth as a blackbody as previously mentioned, Equation 3.4 can be used to estimate the rate at which energy is radiated from the Earth's surface toward the atmosphere. With the surface of Earth at 288K, it will radiate the following amount per unit of surface area

$$\frac{\text{Energy Radiated by Surface}}{\text{Surface Area of Earth}} = \frac{\sigma 4\pi R^2 T_s^4}{4\pi R^2} = \sigma T_s^4 \qquad (3.11)$$

$$= 5.67\times10^{-8}\,\text{W/m}^2\text{K}^4 \times (288\text{K})^4 = 390\,\text{W/m}^2$$

Of the 390 W/m^2, only 40 W/m^2 passes directly through that atmosphere, and the remaining 350 W/m^2 is absorbed by greenhouse gases in the atmosphere. The atmosphere then radiates 324 W/m^2 back to the surface.

There is also heat transfer from the surface to the atmosphere by convective heating and by evaporation and condensation of water. Convection transfers 240 W/m^2 to the atmosphere, while condensation of water vapor provides 78 W/m^2 of latent heat. All of these energy flows are shown in Figure 3.1. If this model is internally self-consistent, the rate of energy gain should be equal to the rate of energy loss in each of the three regions: space, the atmosphere, and the Earth's surface. Consider the following checks:

Rate of energy gain = Rate of energy loss

Earth's surface: 168 + 324 + 30 = 522

78 + 24 + 30 + 390 = 522

Atmosphere: 67 + 78 + 24 + 350 = 519

$$165 + 30 + 324 = 519$$

Space: $107 + 165 + 30 + 40 = 342$

So the model shows the necessary balances

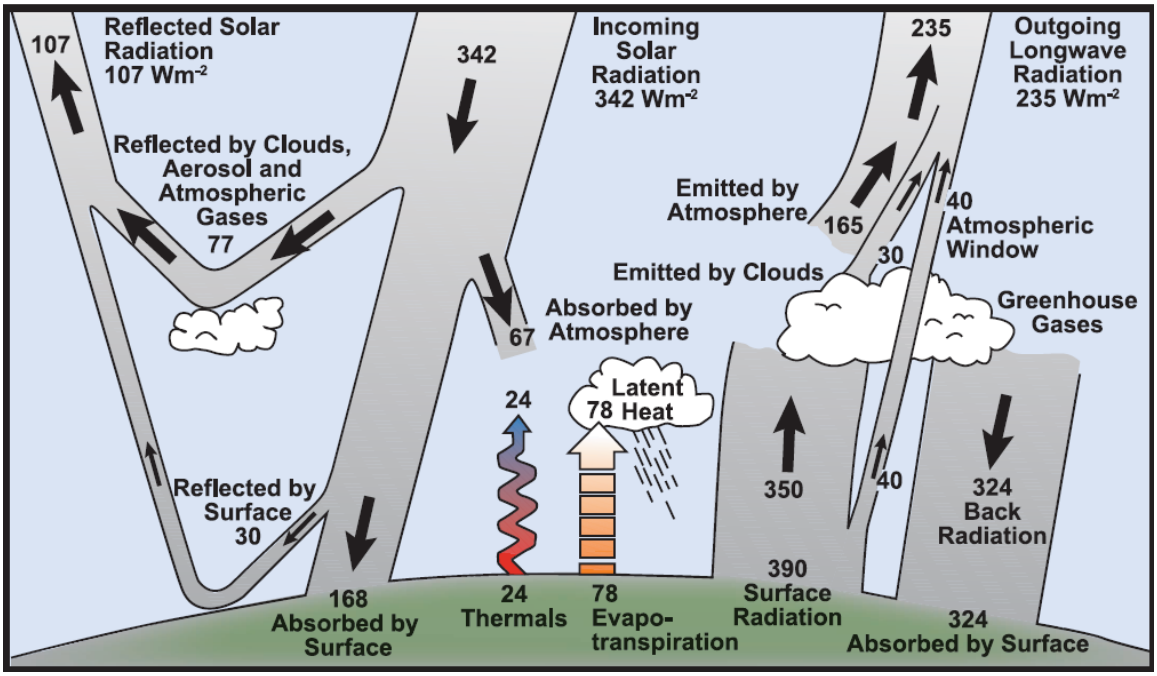

Figure 3.1. Global Average Energy Flows between Space, the Atmosphere, and the Earth Surface. (4)

3.2 Case Study: Cement industry

3.2.1 The study area

Atbara Cement Corporation:

Atbara Cement Corporation was founded in 1974 as a privately owned corporation under the name of Atbara Portland Cement. The company is located 2.5 kilometers north of Atbara Nile Bridge, which is located east of the Nile River, between the road that connects the two cities of Atbara and Aldamar and between the railroads that connects the Nile river district with the capital city, the factory under study runs and functions under the following operating condition; 1,000 tons of Portland cement per day, which is equivalent to an annual production of 240,000 tons provided that the factory is not under normal manufacturing and production process while undergoing maintenance and during holidays and vacations.

3.2.2 Methods and tools used in the case study:

The cement industry being responsible for great portion of all man-made emissions of CO_2, therefore it is important to put great efforts to monitor and decrease CO_2 emissions .Energy savings and GHG emissions reductions in the cement industry can be realized through energy-efficiency retrofits, increased use of blended cements, substitution of fuels, use of waste heat for power generation, and structural shifts (closing older shaft kilns and building modern rotary kilns).

This study focus on the following issues:

- ✓ Fuels

  Fossil fuels used in the product from clinker represent the second largest contribution of carbon dioxide cement from ordinary Portland, Fuels may

be classified as solid, liquid, or gaseous, all three are employed in cement Industry .

Three fuels were selected for the study, because they are common used in Sudan, and they are:

1. Heavy fuel oil
2. Coal
3. Natural gas

- ✓ Kilns and Pre-heaters

The predominant type of kiln used in the cement industry is the rotary kilns, the study focus on the dry straight rotary kilns which commonly used. The kiln can be equipped with a pre-heater, in which the raw meal is preheated with waste heat from the kiln. A type of pre-heater that is especially suitable for the dry kiln is the suspension pre-heater, consisting of multiple preheating stages, in this study five stage pre-heater will be discuss.

- ✓ Raw materials

Limestone is the essential and primary material for manufacturing and production purposes. Its quarry located west of the Nile River and is approximately 20 kilometers away from the western side of the river.

The dominant raw materials in Mahager Atbara for cement manufacture are a rock mixture which is about 80% limestone (Which is rich in $CaCO_3$) and 20% clay or shale (a source of silica, alumina and Fe_2O_3).

3.2.3 Procedure of study:

1. Collect and gather the essential information and data about the production of the factory, fuel types and quantity being used, and the characteristics and properties of the raw limestone, $CaCO_3$.
2. Using the molecular weights from the calcinations chemical equations, calculate the amount of the carbon dioxide, CO_2, resulting from the process of calcinations in the dry rotary kiln.

$$CaCO_3 + Heat \rightarrow CaO + CO_2$$

3. Knowing the amount of C ,calorific value and molecular weight in the fuel, then calculate the amount of carbon dioxide, CO_2, that is produced from the combustion of the furnace fuel (the fuel that is used in the dry rotary kiln),
4. Knowing the amount of C, calorific value and molecular weight in the fuel, then calculate the amount of carbon dioxide, CO_2 that is produced from the combustion of the coal fuel (the alternative fuels).
5. Knowing the amount of C, calorific value and molecular weight in the fuel, then calculate the amount of carbon dioxide, CO_2 that is produced from the combustion of the natural gas fuel, (the alternative fuels).
6. Calculate the amount of CO_2 emitted from each type of fuels mentioned above in step 3 when 5-stage-preheater is used.
7. Gather and tabulate carbon dioxide emission results for comparison.

4. Results & Discussions

4.1 Mathematical modeling:

Among the models investigated, it was found that, the mathematical model developed by Gibert M. Masters. is the suitable for simulating the climate change of the world. The assumption made of considering the world and its atmosphere and out space as three separate regions seems to be logical.

4.2 Atbarah cement factory:

The following information was collected from Atbara cement factory authorities:

- Production per day of Portland cement = 1000 ton.
- Production per year of Portland cement = 240,000 ton.
- Production 1 ton of cement consuming 1.6 ton of Row material.
- Concentration of calcium carbonate ($CaCO_3$) in the raw material = 80%.
- The fuel used is the Heavy Fuel Oil = 9,800 kcal/ kg = 9,800,000 kcal /ton and 86% of carbon.
- Production 1 ton of cement consume 1,250,000 kcal.

Assumptions made:

- Ideal combustion process during which a fuel is burnt completely. (complete fuel combustion)

This case needs sufficient Oxygen and heat to covert all the carbon to carbon dioxide,

- Neglect of non-significant impurities contents that has no effect on global warming (related to air pollution)

- Calculation made on daily production based on 240 working day per year taking into consideration maintenance and vacations

4.2.1Calculation of CO_2 emission from calcinations:

Calculation of Carbon dioxide released during calcinations, CO_2 is released as a by-product which occurs in the upper, cooler end of the kiln, or a precalciner, and results in the conversion of carbonates to oxides. The simplified stoichiometric relationship is as follows:

$$CaCO_3 + Heat \rightarrow CaO + CO_2$$

Producing 1 ton of cement need 1.6 ton of row material which contain 80% $CaCO_3$, that's mean the total amount of calcium carbonate is:

$$CaCO_3 = 1.6 * 0.8 = 1.280 \text{ ton}$$

The molecular weight

$$CaCO_3 \rightarrow CaO + CO_2$$

$CaCO_3 = 100.$

$CaO = 56.$

$CO_2 = 44.$

From the equation

$$1\text{mole of C} + 1\text{mole of } O_2 = 1\text{mol } CO_2$$

Number of moles = Weight in grams/Molecular Weight.

Number of calcium carbonate moles = 1280/100 = 12.8 mole

Then:

$$12.8\ C + 12.8\ O_2 = 12.8\ CO_2$$

$\therefore$ Weight of CO_2 in tons per day = 12.8 * 44 = 563.2 ton/day

$\therefore$ Weight of CO_2 in tons per year = 563.2 * 240 = 135168 ton/year

It's worth mentioning that it is hard to reduce CO_2 emission from calcinations unless reducing the quality of cement to one with less efficiency as example blended cement

4.2.2 Calculation of CO_2 emissions from combustion of fuels:

	Pet-Cock	Heavy Fuel Oil	Natural Gas
Coal(C) %	78	86	75
H2 %	5.0	12	24
O2 %	6.0	1.0	N/A
N %	1.5	1.0	1
Sulfur %	1.0	N/A	N/A
Ash %	8.5	N/A	N/A
Volatile Particles %	3.0	N/A	N/A

Table 4.1 Constituent of fuels

Combustion Equations:

$C + O_2 \rightarrow CO_2$

$C + O_2 \rightarrow CO_2$

$2\ H_2 + O_2 \rightarrow 2H_2O$

$N_2 + 2O_2 \rightarrow 2NO_2$

$S + O_2 \rightarrow SO_2$

It is noticed that carbon monoxide (CO), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) are air pollutant gases and not greenhouse gases (no effect in global warming), for that it will not be calculated and water vapor is a greenhouse gasses but has a little generate in this case equivalents to carbon dioxide, so the calculation will be focused on carbon dioxide (CO_2).

One of the main processes in which carbon dioxide can be produced or resulted is through the combustion of fuel. Fuels have different forms and they are mainly are hydrocarbons chemical compounds. . In the combustion reaction, a compound reacts with an oxidizing element, such as oxygen.

The chemical reaction of combustion of fuels is rather simple. It requires the existence of oxygen with the fuel to be burned. Stated in words as follows;

Fuel + Air → Heat + Water + Carbon dioxide

- **Heavy Fuel Oil (furnace)(the fuel used)**

Heavy Fuel Oil (furnace) = 9,800,000 kcal/ton

Production of 1 ton of cement consume 1,250,000 kcal

That's mean consumption of fuel per ton production calculated as

1,250,000/9,800,000 = 0.127551 ton of fuel

1000 ton production of cement per day consume

0.127551 * 1000 = 127.551 ton of fuel

Heavy fuel oil content of 86% carbon (C)

That's mean combustion of carbon per day calculated as

127.551 * 0.86 = 109.693 ton/day

The equation of carbon combustion in fuel

$$C + O_2 \rightarrow CO_2$$

The molecular weights are as follows:

C = 12

O_2 = 32

CO_2 = 44

From the equation

1mole of C + 1mole of O_2 = 1mol CO_2

Number of moles = Weight in grams/Molecular Weight.

Number of carbon moles = 109.693/12 = 9.141 mole

Then:

$$9.141\ C + 9.141\ O_2 = 9.141\ CO_2$$

∴ Weight of CO_2 in tons per day = 9.141 * 44 = 402.204 ton/day

∴ Weight of CO_2 in tons per year = 402.204 * 240 = 96528.96 ton/year

Actual emission of CO_2 from Atbara cement factory:

Total of CO_2 emission =

CO_2 emitted from calcinations + CO_2 emitted from fuel combustion

∴ CO_2 emitted per day = 563.2 + 402.204 = 965.404 ton / day

CO_2 emitted per year = 135168 + 96528.96 = 231696.96 ton / year

4.2.3 Alternative fuels

- **Natural gas**

Natural gas = 10320000 kcal/ton

1 ton of cement consume 1,250,000 kcal in production

That's mean consumption of fuel per ton production calculated as

1,250,000/10320000 = 0.1211 ton of fuel

1000 ton production of cement per day consume

0.1211 * 1000 = 121.1 ton of fuel per day

Natural gas content of 75% carbon (C)

That's mean combustion of carbon per day calculated as

121.1 * 0.75 = 90.825 ton/day

The equation of carbon combustion in fuel

$$C + O_2 \rightarrow CO_2$$

The molecular weights are as follows

C = 12

O_2 = 32

CO_2 = 44

From the equation

1mole of C + 1mole of O_2 = 1mol CO_2

Number of moles=Weight in grams/Molecular Weight.

Number of carbon moles=90.825/12=7.568 mole

Then:

7.568 C + 7.568 O_2 = 7.568 CO_2

∴ Weight of CO_2 in tons per day=7.568 * 44 = 332.992 ton/day

∴ Weight of CO_2 in tons per year =332.992 * 240 = 79918.08 ton/year

- **Petcock**

Petcock = 7216000 kcal/ton

1 ton of cement consume 1,250,000 kcal in production

That's mean consumption of fuel per ton production calculated as

1,250,000/7216000 = 0.173226 ton of fuel

1000 ton production of cement per day consume

0.173226 * 1000 = 173.226 ton of fuel

Petcock content of 78% carbon(C)

That's mean combustion of carbon per day calculated as

173.226 * 0.78 = 135.116 ton/day

The equation of carbon combustion in fuel

$C + O_2 \rightarrow CO_2$

The molecular weights are as follows

C = 12

$O_2 = 32$

$CO_2 = 44$

From the equation

1mole of C+1mole of O_2=1mol CO_2

Number of moles=Weight in grams/Molecular Weight.

Number of carbon moles=135.116 /12 = 11.259 mole

Then:

$$11.259\ C + 11.259\ O_2 = 11.259\ CO_2$$

$\therefore$ Weight of CO_2 in tons per day =11.259 * 44 = 495.396 ton/day

$\therefore$ Weight of CO_2 in tons per year = 495.396 * 240 =118895.04 ton/year

It's obvious that using of petcock fuel as an alternative fuel produce 23.17% more carbon dioxide than heavy fuel oil.

In spite of petcock is available as secondary product in the refinery and has low cost, but has obvious effect on global warming.

4.2.4 Calculation of CO_2 emission from fuel incase of adding five stage Pre-heater

- **Heavy Fuel Oil**

  Heavy fuel oil (furnace) =9,800,000 kcal/ton

  In this case production of 1 ton of cement consume 850000 kcal instead of 1250000 kcal (incase of adding five stage pre-heater). That's mean consumption of fuel per ton production calculated as

$$850000/9{,}800{,}000 = 0.0867 \text{ ton of fuel}$$

1000 ton production of cement per day consume

$$0.0867 * 1000 = 86.7 \text{ ton of fuel}$$

Heavy fuel oil content of 86% carbon(C)

That's mean combustion of carbon per day calculated as

$$86.7 * 0.86 = 74.562 \text{ ton/day}$$

The equation of carbon combustion in fuel

$$C + O_2 \rightarrow CO_2$$

The molecular weights are as follows

C = 12

O_2 = 32

CO_2 = 44

From the equation

1mole of C+1mole of O_2 = 1mol CO_2Number of moles=Weight in grams/Molecular Weight.

Number of carbon moles = 74.562/12 = 6.2135 mole

Then:

$$6.2135\ C + 6.2135\ O_2 = 6.2135\ CO_2$$

$\therefore$ Weight of CO_2 in tons per day = 6.2135 * 44 = 273.394 ton/day

$\therefore$ Weight of CO_2 in tons per year = 273.394 * 240 = 65614.56 ton/year

- **Natural Gas**

Natural gas = 10320000 kcal/ton

1 ton of cement consume 850000 kcal in production (incase of adding five stage pre-heater). That's mean consumption of fuel per ton production calculated as

$$850000 / 10320000 = 0.082364 \text{ ton of fuel}$$

1000 ton production of cement per day consume

$$0.082364 * 1000 = 82.364 \text{ ton of fuel}$$

Natural gas content of 75% carbon (C). That's mean combustion of carbon per day calculated as

$$82.364 * 0.75 = 61.77325 \text{ ton/day}$$

The equation of carbon combustion in fuel

$$C + O_2 \rightarrow CO_2$$

The molecular weights are as follows

C = 12

O_2 = 32

CO_2 = 44

From the equation

$$1\text{mole of C} + 1\text{mole of } O_2 = 1\text{mol } CO_2$$

Number of moles = Weight in grams/Molecular Weight.

Number of carbon moles = 61.77325 /12 = 5.1477 mole

Then:

$$5.1477\ C + 5.1477\ O_2 = 5.1477\ CO_2$$

$\therefore$ Weight of CO_2 in tons per day = 5.1477 * 44 = 226.5019 ton/day

$\therefore$ Weight of CO_2 in tons per year = 226.5019 * 240 = 54360.464 ton/year

- **Petcock**

Petcock=7216000 kcal/ton

1 ton of cement consume 850000 kcal in production (incase of adding five stage pre-heater). That's mean consumption of fuel per ton production calculated as

$$850000 /7216000 = 0.117793 \text{ ton of fuel}$$

1000 ton production of cement per day consume

$$0.117793 * 1000 = 117.793 \text{ ton of fuel}$$

Petcock content of 78% carbon (C). That's mean combustion of carbon per day calculated as

$$117.793 * 0.78 = 91.878 \text{ ton/day}$$

The equation of carbon combustion in fuel

$$C + O_2 \rightarrow CO_2$$

The molecular weights are as follows

C = 12

O_2 = 32

CO_2 = 44

From the equation

$$1\text{mole of C} + 1\text{mole of } O_2 = 1\text{mol } CO_2$$

Number of moles = Weight in grams/Molecular Weight.

Number of carbon moles = 91.878 /12 = 7.656 mole

Then:

$$7.656\ C + 7.656\ O_2 = 7.656\ CO_2$$

$\therefore$ Weight of CO_2 in tons per day = 7.656 * 44 = 336.887 ton/day

$\therefore$ Weight of CO_2 in tons per year = 336.887 * 240 = 80853.115 ton/year

Source of CO_2 Emission	CO_2 Emission without pre-heater (ton/day)	CO_2 Emission with pre-heater (ton/day)	CO_2 Emission without pre-heater (ton/yr)	CO_2 Emission with pre-heater (ton/yr)
Calcinations	563.200	563.200	135168.00	135168.00
Heavy Fuel Oil	402.204	273.394	96528.96	65614.56
Pet-cock	495.396	336.887	118895.04	80853.115
Natural Gas	332.992	226.502	79918.08	54360.46

Table 4.2. Comparison for Different CO_2-Emitting-Sources

Table 4.2 shows a comparison of different CO_2-emittting-sources and the amount of CO_2 each source emits when burned. The table revealed that Natural gas is the lowest producer for CO_2 which produce 32.78% less than petcock and 17.2% less than heavy fuel oil while petcock produce 18.81% CO_2 more than heavy fuel oil.

In addition to the above, it was found that adding five stages pre-heaters reduced consumption of fuel and reduced emission of carbon dioxide to 32.02%.

5. Conclusions & Recommendations

5.1 Conclusions

It is important to follow the most recent international data on climate change and to try adopting it for the case of Sudan which is huge country with different climatic conditions. It is also important to disseminate the culture of reducing the global warming.

As far as, cement industry is concerned it was found that:

1. Natural gas is the cleanest of all the fossil fuels discussed.
2. Total amount of CO_2 emitted from calcinations and combustion equal to 965.404 ton/day and 231696.96 ton / year.
3. The amount of CO_2 emitted from calcinations equal to 563.200ton/day and 135168.00 ton/year.
4. The amount of CO_2 emitted from combustion of fuels equal to 402.204 ton/day and 96528.96 ton/year.
5. In case of using natural gas as an alternative fuels , CO_2 emitted will be equal to 332.992 ton/day and 79918.08 ton/year which is equivalent to 17.2% less than the one in use (heavy fuel oil).
6. Incase of using petcock as an alternative fuels, CO_2 emitted will be equal to 495.396 ton/day and 118895.04 ton/year which is equivalent to 18.81% more than the one in use (heavy fuel oil).
7. Using five stages pre-heater the total amount of CO_2 emitted from calcinations and combustion equal to 836.594 ton/day and 200782.56 ton / year which is equivalent to 13.34% less than the case of without using pre-heater.

5.2 Recommendations

The study recommended the dissemination of global warming and climate change culture.

To reduce the influence and contribution of cement industry to global warming, it is recommended:

1. To add a pre-heater to kilns.
2. To use an alternative fuel (natural gas) instead of fossil fuels.
3. To develop alternative cement products, and replace Portland cement.
4. Minimize emission of CO2 through use of biofuels and absorption.

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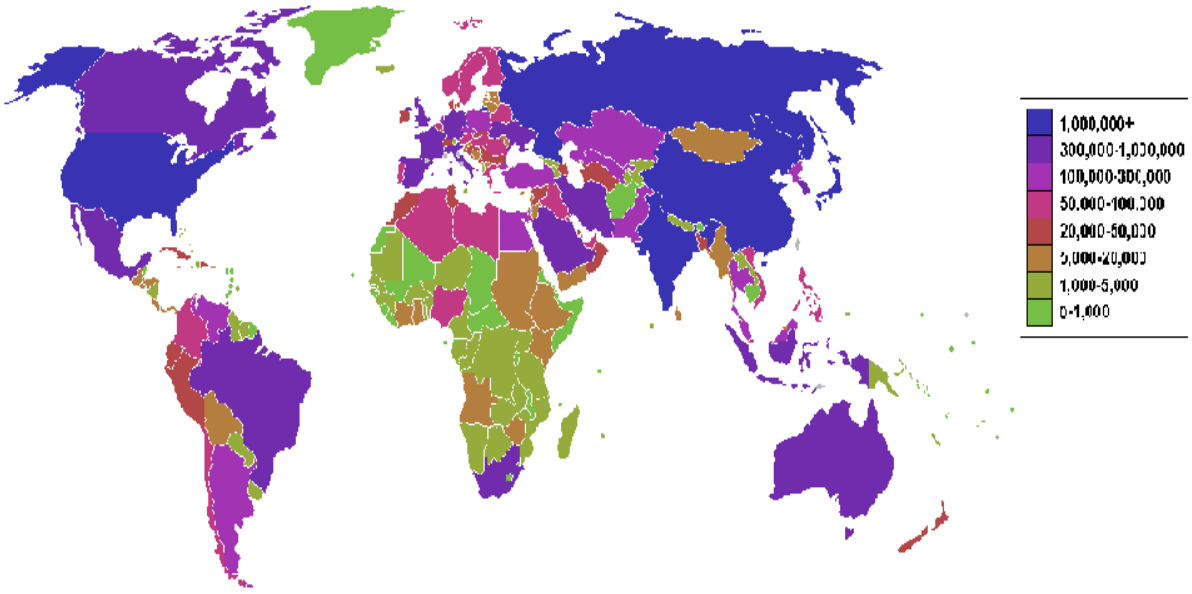
APPENDIX

Attachment 1.

Carbon Emissions by Country



Attachment 2.

Rank	Country	Annual CO_2 *emissions* in thousands of metric tons	Percentage of total emissions[4]
-	World	27,245,758	100.0 %
1	United States [5]	6,049,435	22.2 %
2	China	5,010,170	18.4 %
-	*European Union*	3,115,125	11.4 %
3	Russia	1,524,993	5.6 %
4	India	1,342,962	4.9 %
5	Japan	1,257,963	4.6 %
6	Germany	808,767	3.0 %
7	Canada	639,403	2.3 %
8	United Kingdom	587,261	2.2 %
9	South Korea	465,643	1.7 %
10	Italy [6]	449,948	1.7 %
11	Mexico	438,022	1.6 %
12	South Africa	437,032	1.6 %
13	Iran	433,571	1.6 %
14	Indonesia	378,250	1.4 %
15	France [7]	373,693	1.4 %
16	Brazil	331,795	1.2 %
17	Spain	330,497	1.2 %
18	Ukraine	330,039	1.2 %
19	Australia	326,757	1.2 %
20	Saudi Arabia	308,393	1.1 %
21	Poland	307,238	1.1 %
22	Thailand	268,082	1.0 %
23	Turkey	226,125	0.8 %
24	Kazakhstan	200,278	0.7 %
25	Algeria	194,001	0.7 %
26	Malaysia	177,584	0.7 %
27	Venezuela	172,623	0.6 %
28	Egypt	158,237	0.6 %
29	United Arab Emirates	149,188	0.5 %
30	Netherlands	142,061	0.5 %
31	Argentina	141,786	0.5 %

Rank	Country	Annual CO_2 *emissions* in thousands of metric tons	Percentage of total emissions[4]
32	Uzbekistan	137,907	0.5 %
33	Pakistan	125,669	0.5 %
34	Czech Republic	116,991	0.4 %
35	Nigeria	114,025	0.4 %
36	Belgium	100,716	0.4 %
37	Kuwait	99,364	0.4 %
38	Vietnam	98,663	0.4 %
39	Greece	96,695	0.4 %
40	Romania	90,425	0.3 %
41	Norway	87,602	0.3 %
42	Iraq	81,652	0.3 %
43	Philippines	80,512	0.3 %
44	North Korea	79,111	0.3 %
45	Israel	71,247	0.3 %
46	Austria	69,846	0.3 %
47	Syria	68,420	0.3 %
48	Finland	65,799	0.2 %
49	Belarus	64,890	0.2 %
50	Chile	62,418	0.2 %
51	Libya	59,914	0.2 %
52	Portugal	58,906	0.2 %
53	Hungary	57,183	0.2 %
54	Colombia	53,634	0.2 %
55	Serbia and Montenegro	53,322	0.2 %
56	Sweden	53,033	0.2 %
57	Denmark	52,956	0.2 %
58	Qatar	52,904	0.2 %
59	Singapore	52,252	0.2 %
60	Bulgaria	42,558	0.2 %
61	Ireland	42,353	0.2 %
62	Turkmenistan	41,726	0.2 %
63	Morocco	41,169	0.2 %
64	Switzerland	40,457	0.2 %

Rank	Country	Annual CO_2 *emissions* in thousands of metric tons	Percentage of total emissions[4]
65	Hong Kong	37,411	0.1 %
66	Bangladesh	37,165	0.1 %
67	Slovakia	36,289	0.1 %
68	Trinidad and Tobago	32,557	0.1 %
69	New Zealand	31,570	0.1 %
70	Peru	31,493	0.1 %
71	Azerbaijan	31,365	0.1 %
72	Oman	30,899	0.1 %
73	Ecuador	29,268	0.1 %
74	Cuba	25,818	0.1 %
75	Croatia	23,501	0.1 %
77	Tunisia	22,885	0.1 %
78	Yemen	21,114	0.1 %
79	Dominican Republic	19,640	0.1 %
80	Estonia	18,944	0.1 %
81	Bahrain	16,949	0.1 %
82	Jordan	16,465	0.1 %
83	Lebanon	16,263	0.1 %
84	Slovenia	16,212	0.1 %
85	Bosnia and Herzegovina	15,596	0.1 %
86	Lithuania	13,309	0.1 %
87	Guatemala	12,220	0.1 %
88	Sri Lanka	11,534	<0.1 %
89	Luxembourg	11,277	<0.1 %
90	Jamaica	10,592	<0.1 %
91	Kenya	10,588	<0.1 %
92	Zimbabwe	10,559	<0.1 %
93	Republic of Macedonia	10,420	<0.1 %
94	Sudan	10,372	<0.1 %
95	Myanmar	9,760	<0.1 %
96	Brunei	8,810	<0.1 %
97	Mongolia	8,553	<0.1 %
98	Ethiopia	7,982	<0.1 %
99	Angola	7,897	<0.1 %
100	Moldova	7,685	<0.1 %

Rank	Country	Annual CO_2 *emissions* in thousands of metric tons	Percentage of total emissions[4]
100	Moldova	7,685	<0.1 %
101	Honduras	7,615	<0.1 %
102	Ghana	7,190	<0.1 %
103	Latvia	7,098	<0.1 %
104	Bolivia	6,973	<0.1 %
105	Cyprus	6,750	<0.1 %
106	Costa Rica	6,405	<0.1 %
107	El Salvador	6,167	<0.1 %
108	Kyrgyzstan	5,727	<0.1 %
109	Panama	5,661	<0.1 %
110	Uruguay	5,477	<0.1 %
111	Equatorial Guinea	5,426	<0.1 %
112	Côte d'Ivoire	5,162	<0.1 %
113	Tajikistan	5,004	<0.1 %
114	Senegal	4,993	<0.1 %
115	Tanzania	4,352	<0.1 %
116	Botswana	4,301	<0.1 %
117	Paraguay	4,180	<0.1 %
118	Netherlands Antilles	4,088	<0.1 %
119	Nicaragua	4,007	<0.1 %
120	Georgia	3,912	<0.1 %
121	Cameroon	3,839	<0.1 %
122	Albania	3,674	<0.1 %
123	Armenia	3,648	<0.1 %
124	Republic of the Congo	3,542	<0.1 %
125	Mauritius	3,197	<0.1 %
126	Nepal	3,043	<0.1 %
127	Madagascar	2,731	<0.1 %
128	New Caledonia	2,577	<0.1 %
129	Mauritania	2,555	<0.1 %
130	Namibia	2,471	<0.1 %
131	Malta	2,453	<0.1 %
132	Papua New Guinea	2,449	<0.1 %
133	Benin	2,387	<0.1 %
134	Togo	2,310	<0.1 %

Rank	Country	Annual CO_2 *emissions* in thousands of metric tons	Percentage of total emissions[4]
135	Zambia	2,288	<0.1 %
136	Suriname	2,284	<0.1 %
137	Réunion	2,277	<0.1 %
138	Iceland	2,229	<0.1 %
139	Macau	2,207	<0.1 %
140	Mozambique	2,167	<0.1 %
141	Aruba	2,156	<0.1 %
142	Democratic Republic of the Congo	2,104	<0.1 %
143	Bahamas	2,009	<0.1 %
144	Uganda	1,826	<0.1 %
145	Haiti	1,756	<0.1 %
146	Guadeloupe	1,734	<0.1 %
147	Guyana	1,445	<0.1 %
148	Gabon	1,371	<0.1 %
149	Guinea	1,338	<0.1 %
150	Martinique	1,291	<0.1 %
151	Laos	1,280	<0.1 %
152	Barbados	1,269	<0.1 %
153	Niger	1,214	<0.1 %
154	Burkina Faso	1,096	<0.1 %
155	Fiji	1,071	<0.1 %
156	Malawi	1,045	<0.1 %
157	French Guiana	1,005	<0.1 %
158	Sierra Leone	994	<0.1 %
159	Swaziland	957	<0.1 %
160	Belize	792	<0.1 %
161	Eritrea	755	<0.1 %
162	Maldives	726	<0.1 %
163	Afghanistan	693	<0.1 %
164	French Polynesia	671	<0.1 %
165	Faroe Islands	660	<0.1 %
166	Palestinian Authority	649	<0.1 %
167	Greenland	572	<0.1 %

Rank	Country	Annual CO_2 *emissions* in thousands of metric tons	Percentage of total emissions[4]
168	Rwanda	572	<0.1 %
169	Mali	565	<0.1 %
170	Bermuda	550	<0.1 %
171	Seychelles	546	<0.1 %
172	Cambodia	535	<0.1 %
173	Liberia	470	<0.1 %
174	Bhutan	414	<0.1 %
175	Antigua and Barbuda	414	<0.1 %
176	Gibraltar	374	<0.1 %
177	Saint Lucia	367	<0.1 %
178	Djibouti	367	<0.1 %
179	Cayman Islands	312	<0.1 %
180	Gambia	286	<0.1 %
181	Cape Verde	275	<0.1 %
182	Guinea-Bissau	271	<0.1 %
183	Central African Republic	253	<0.1 %
184	Sahrawi Arab Democratic Republic	238	<0.1 %
185	Palau	238	<0.1 %
186	Burundi	220	<0.1 %
187	Grenada	216	<0.1 %
188	Saint Vincent and the Grenadines	198	<0.1 %
189	Timor-Leste	176	<0.1 %
190	Solomon Islands	176	<0.1 %
191	Samoa	150	<0.1 %
192	Nauru	143	<0.1 %
193	Saint Kitts and Nevis	125	<0.1 %
194	Chad	125	<0.1 %
195	Tonga	117	<0.1 %
196	Dominica	106	<0.1 %
197	São Tomé and Príncipe	92	<0.1 %
198	Vanuatu	88	<0.1 %
199	Comoros	88	<0.1 %
200	British Virgin Islands	84	<0.1 %
201	Saint Pierre and Miquelon	62	<0.1 %
202	Montserrat	62	<0.1 %
203	Falkland Islands	44	<0.1 %
204	Kiribati	29	<0.1 %

Rank	Country	Annual CO_2 *emissions* in thousands of metric tons	Percentage of total emissions[4]
205	Cook Islands	29	<0.1 %
206	Saint Helena	11	<0.1 %
207	Niue	4	<0.1 %

Attachment .3

Changes in GHG emissions from 1990 to 2004 for Annex I Parties

Party	Total GHG emissions without LULUCF (Tg / million tonnes CO_2 equivalent)			Changes in emissions (%)		Emission reduction target under the Kyoto Protocol[a, b]
	1990	2000	2004	1990–2004	2000–2004	(%)
Australia	423.1	504.2	529.2	25.1	5.0	–[c]
Austria	78.9	81.3	91.3	15.7	12.4	–8 (–13)
Belarus	127.4	69.8	74.4	–41.6	6.6	no target yet
Belgium	145.8	147.4	147.9	1.4	0.3	–8 (–7.5)
Bulgaria	132.3	64.3	67.5	–49.0	5.1	–8
Canada	598.9	725.0	758.1	26.6	4.6	–6
Croatia	31.1	25.3	29.4	–5.4	16.5	–[c]
Czech Republic	196.2	149.2	147.1	–25.0	–1.4	–8
Denmark	70.4	69.6	69.6	–1.1	0.1	–8 (–21)
Estonia	43.5	19.7	21.3	–51.0	8.4	–8
European Community	4252.5	4129.3	4228.0	–0.6	2.4	–8
Finland	71.1	70.0	81.4	14.5	16.4	–8 (0)
France	567.1	561.4	562.6	–0.8	0.2	–8 (0)
Germany	1226.3	1022.8	1015.3	–17.2	–0.7	–8 (–21)
Greece	108.7	131.8	137.6	26.6	4.5	–8 (+25)
Hungary	123.1	81.9	83.9	–31.8	2.5	–6
Iceland	3.28	3.54	3.11	–5.0	–12.2	+10
Ireland	55.6	68.7	68.5	23.1	–0.4	–8 (+13)
Italy	519.6	554.6	582.5	12.1	5.0	–8 (–6.5)
Japan	1272.1	1345.5	1355.2	6.5	0.7	–6
Latvia	25.9	9.9	10.7	–58.5	8.2	–8
Liechtenstein	0.229	0.256	0.271	18.5	6.0	–8
Lithuania	50.9	20.8	20.2	–60.4	–3.1	–8
Luxembourg	12.7	9.7	12.7	0.3	31.3	–8 (–28)
Monaco	0.108	0.117	0.104	–3.1	–11.0	–8
Netherlands	213.0	214.4	218.1	2.4	1.7	–8 (–6)
New Zealand	61.9	70.3	75.1	21.3	6.8	0
Norway	49.8	53.5	54.9	10.3	2.7	+1
Poland	564.4	386.2	388.1	–31.2	0.5	–6
Portugal	60.0	82.2	84.5	41.0	2.9	–8 (+27)
Romania	262.3	131.8	154.6	–41.0	17.3	–8
Russian Federation	2974.9	1944.8	2024.2	–32.0	4.1	0
Slovakia	73.4	49.4	51.0	–30.4	3.3	–8
Slovenia	20.2	18.8	20.1	–0.8	6.6	–8
Spain	287.2	384.2	427.9	49.0	11.4	–8 (+15)
Sweden	72.4	68.4	69.9	–3.5	2.1	–8 (+4)
Switzerland	52.8	51.7	53.0	0.4	2.6	–8
Turkey	170.2	278.9	293.8	72.6	5.3	–[c]
Ukraine	925.4	395.1	413.4	–55.3	4.6	0
United Kingdom	776.1	672.2	665.3	–14.3	–1.0	–8 (–12.5)
United States	6103.3	6975.9	7067.6	15.8	1.3	–[c]
Annex I EIT Parties	5551.0	3366.9	3506.0	–36.8	4.1	–
Annex I non-EIT Parties	13000.5	14147.7	14425.6	11.0	2.0	–
All Annex I Parties to the Convention	18551.5	17514.6	17931.6	–3.3	2.4	–
Annex I Kyoto Protocol Parties	11823.8	9730.3	10011.5	–15.3	2.9	–5

[a] The national reduction targets as per the "burden-sharing" agreement of the European Community are shown in parentheses.
[b] The national reduction targets relate to the first commitment period under the Kyoto Protocol, which is from 2008 to 2012.
[c] A Party to the Climate Change Convention but not a Party to the Kyoto Protocol.
Note: base year data (under the Climate Change Convention) are used here instead of 1990 data (as per COP decisions 9/CP.2 and 11/CP.4) for Bulgaria (1988), Hungary (average of 1985–1987), Poland (1988), Romania (1989) and Slovenia (1986).